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STATE GEOLOGICAL SURVEY

F. W. DEWOLF, Director

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Portland-Cement Resources of Illinois

BY

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STATE GEOLOGICAL COMMISSION.

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STATE GEOLOGICAL SURVEY,
UNIVERSITY OF ILLINOIS, Feb. 1, 1912.

Governor C. S. Deneen, Chairman, and Members of the Geological Commission:

GENTLEMEN—I submit herewith a report on Portland-cement resources of Illinois, and recommend that it be published as Bulletin No. 17.

This represents a special effort to determine the location of materials of suitable character for the manufacture of Portland cement. It is essentially preliminary, but serves to bring together the analyses of many samples which have been collected since the Survey's organization. The field work on limestones was done by various members of the staff, at various times, but the investigation on shale and clay was mostly carried on by Mr. F. E. Layman during the season of 1908.

The chapters on cement materials and technology were prepared by Professor A. V. Bleininger, now head of the Department of Ceramics at the University, and a recognized authority on cement manufacture. The chapters on geological relations and on the occurrence of limestone were compiled by Mr. E. F. Lines, formerly of the Survey staff. The work has been handicapped by changes in personnel during the time of its execution, but the report will doubtless serve a very useful purpose in view of the growing use of Portland cement and the many inquiries on the subject by land owners and investors.

Very respectfully,
FRANK W. DEWOLF,
Director.

CHAPTER I—ILLINOIS PORTLAND-CEMENT INDUSTRY.

(By A. V. Bleininger.)

The development of the Portland-cement industry in Illinois has closely resembled its growth throughout the country. The production in the United States has shown an extraordinarily rapid growth during the last fifteen years. This was to be expected, owing to the fact that the industry prior to 1890 produced only a small proportion of the Portland cement used. The cutting down of the importation of cement and to a far greater extent the increase in population and the multiplication of the uses of concrete have brought about an enormous demand for Portland cement, which has been met promptly by the industry. The rate of increase in the production is bound to be lowered within the next few years since demand and supply are not far from being balanced at the present time. The whole question will reduce itself to the elimination of plants poorly located, or inefficiently designed or operated, and new plants can hope to succeed only if possessed of a very favorable natural location commanding large deposits of easily quarried and worked raw materials, cheap fuel, and satisfactory markets. If, however, a company erects a well designed mill under such conditions, its investment is practically certain to be a safe one.

The selling price of Portland cement is decreasing rapidly. But recently the writer has seen quotations as low as 75 cents per barrel at the mill.

The following tabulation gives the production in barrels and the valuation, both for Illinois and for the United States, as published by the U. S. Geological Survey (Pl. I.):

Production of Portland cement, 1900-1910.

	Illinois.		United States.	
	Barrels.	Value.	Barrels.	Value.
1900	240,442	$ 300,552	8,482,020	$ 9,280,525
1901	528,925	581,818	12,711,225	12,532,360
1902	767,781	977,541	17,230,644	20,864,078
1903	1,257,500	1,914,500	22,342,973	27,713,319
1904	1,326,794	1,449,114	26,505,881	23,355,119
1905	1,545,500	1,741,150	35,246,812	33,245,867
1906	1,858,403	2,461,494	46,463,424	52,466,186
1907	2,036,093	2,632,576	48,785,390	53,992,551
1908	3,211,168	2,707,044	51,072,612	43,547,679
1909	4,241,392	3,388,667	64,991,431	52,858,354
1910	4,459,450	4,119,012	76,549,951	68,205,800

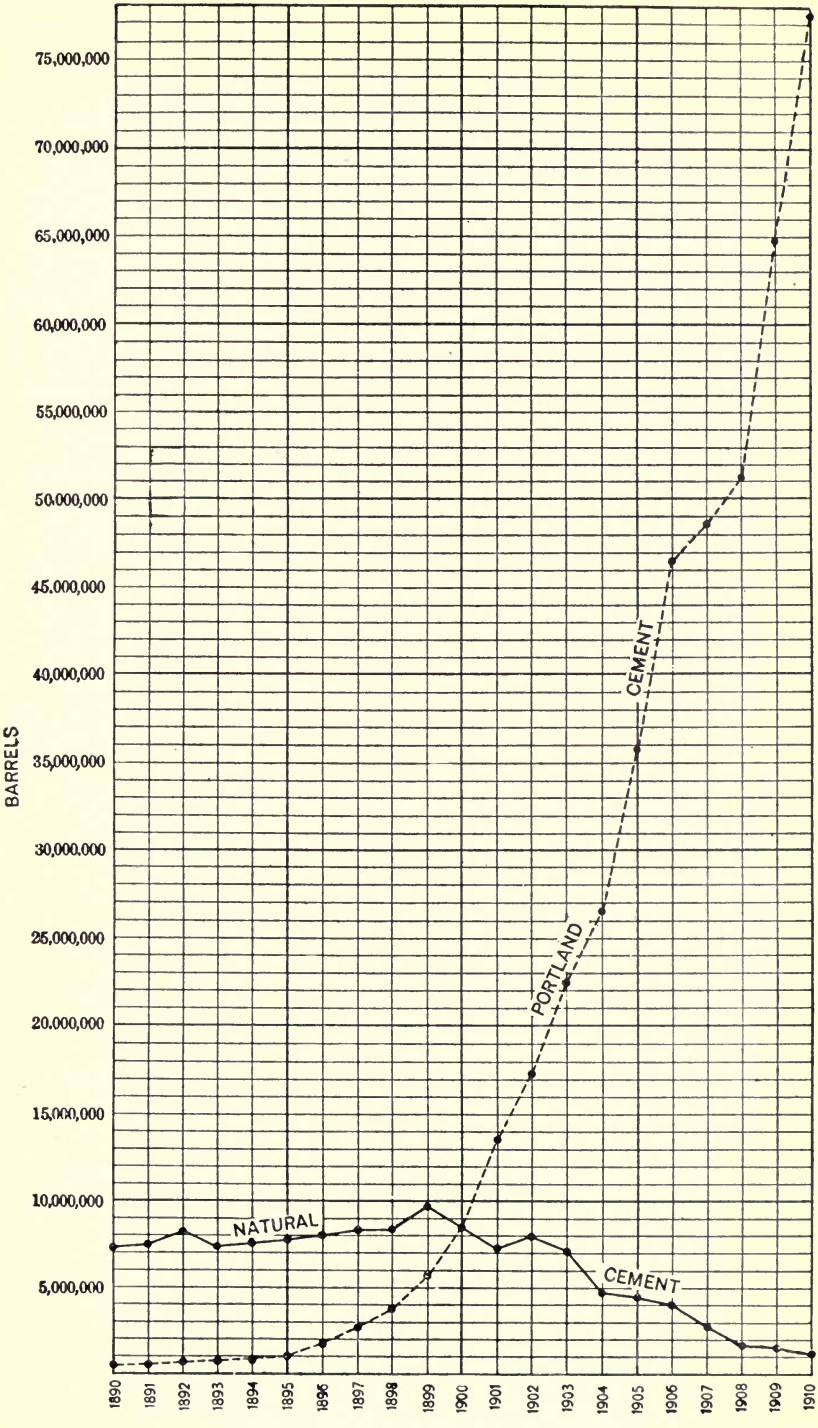
With reference to the average price at the mill, excluding cost of package but including cost of packing, the following table is quoted from the 1910 report of the U. S. Geological Survey:

Average price per barrel of Portland cement.

1898	$1.62	1905	$0.94
1899	1.43	1906	1.13
1900	1.09	1907	1.11
1901	0.99	1908	0.85
1902	1.21	1909	0.813
1903	1.24	1910	0.891
1904	0.88		

The Illinois Portland-cement plants are arranged alphabetically as follows: The Chicago Portland Cement Co., and the German American Portland Cement Co. near LaSalle; the Marquette Portland Cement Co. at Oglesby; the Sandusky Portland Cement Co. at Dixon; and the Universal Portland Cement Co. at South Chicago. All use limestone and clay with the dry process, with the exception of the last-named company, which uses granulated blast-furnace slag, together with limestone as raw materials.

With the increasing population of the middle West, the demand for Portland cement is bound to grow; and the possibilities are excellent for the further development of this industry in the State. With cheap coal, limestone and clay deposits in sufficient quantities, and good transportation facilities, there is no reason why there should not be more cement mills in western and southern Illinois. It is important to keep in mind, however, that the cement industry has reached a stage where large profits are out of the question; and that dividends depend principally upon favorable location and close economy in factory operation.



Production of Portland and natural cement in the United States, 1890-1910.

CHAPTER II—THE RAW MATERIALS FOR PORTLAND CEMENT.

(By A. V. Bleininger.)

DEFINITION OF PORTLAND CEMENT.

Portland cement is a granular powder, which when mixed with water, forms a coherent mass. This hardens in air, as well as in water, and shows great cementing power. It is the strongest hydraulic cementing substance known; and as commonly mixed with sand and rock aggregate it forms concrete. Portland cement is an artificial product formed by grinding together intimately clay and lime-bearing materials so that the resultant mixture has a well-defined chemical composition. The ground mixture is then calcined to vitrification and again reduced to a specified degree of fineness. It matters little what materials make up this mixture, provided that the chemical composition comes within the prescribed limits, and that the grinding is fine enough to blend the raw materials intimately. On the other hand, failure to comply with these two conditions results in a low-grade product. It is frequently difficult to gain the desired reaction on a commercial basis at the temperature available in industrial kilns.

The required clay bases are introduced in the form of various classes of clays, blast-furnace slags, and even volcanic ash, tufa, and similar materials. The lime is introduced as limestone, chalk, calcareous marl, fossil lime, and as the by-products of industrial chemical processes—like the Solvay wastes.

CLAY MATERIALS.

Since the aluminum silicates of clay, or of allied mineral aggregates, form the fundamental part of Portland cement, a brief consideration of the mineralogical structure of clay is necessary for the understanding of the chemical processes connected with the production of hydraulic silicates.

Definition of Clay.

Clay may be defined as a complex derivative rock, generally of a soft and earthy nature, in which a mass of mineral debris of variable composition and amount is bonded and held together by a matrix of kaolin, or allied hydrous silicates of alumina. The distinguishing characteristics of clays as a class are, first, plasticity when ground and mixed with sufficient amount of water; and second, the property of hardening by heat to form strong and durable silicates. This definition is not exact, for there are minor exceptions to each rule. For the purpose of the cement manufacturer the hardening of clay upon heating is of no practical importance.

ORIGIN AND CONSTITUENTS OF CLAY.

All clays are the product of decomposition of the older igneous rocks of which the granites are most representative. These rocks may contain quartz, feldspar, mica, hornblende, augite, magnetite, and various other minerals. When subjected to the destructive agencies of weathering for long periods decomposition of the granite takes place, and it is evident that the mineral offering least resistance is attacked first. This is usually feldspar; which succumbs first so that, gradually, its chemical structure is completely changed. The typical feldspar—orthoclase—possesses the chemical formula $K_2O.\ Al_2O_3.\ 6\ SiO_2$, and the following composition:

Composition of orthoclase feldspar.

Silica (SiO_2)	64.68
Alumina (Al_2O_3)	18.43
Potash (K_2O)	16.89

It is metamorphosed into a mineral type having the formula $Al_2O_3.\ 2\ SiO_2.\ 2\ H_2O$, and the following composition:

Composition of clay substance.

Silica (SiO_2)	46.3
Alumina (Al_2O_3)	39.8
Combined water	13.9

This mineral is called *kaolin* and represents the purest grade of clay. It may, therefore, serve to illustrate the chemical structure and behavior of the fundamental part of all clays—the clay substance. Before considering this subject, however, it must be borne in mind that the kaolin produced by the breaking down of the granite is not separated sharply from the other constituents of the rock, but that some undecomposed particles of quartz, feldspar, mica, and other minerals remain in all grades of subdivision with the newly formed clay. The pure clay, or kaolin, consists of silica, alumina, and chemically combined water. which together form a hydrous silicate of alumina. This compound varies as regards plasticity according to whether it is crystalline or amorphous, and highly or weakly colloidal. Kaolin may be present in the form of regular crystals, in which case it shows but a low degree of plasticity, or it may exist as a jelly-like mass resembling gelatine, aluminum hydroxide, ferric hydroxide, etc. The more this colloidal character is exhibited, the more plastic is the kaolin. This physical condition has nothing to do with the chemical composition which in either case may correspond to the ideal formula.

CLAY SUBSTANCE.

The clay substance consisting of the complex molecule $Al_2O_3.\ 2\ SiO_2.\ 2\ H_2O$, may be decomposed under the action of strong reagents into alumina and silica. Thus, hot sulphuric acid dissociates pure kaolin completely, leaving hydrous silicic acid, partly in solution and partly precipitated, and bringing the alumina into solution as aluminum sulphate. Again, while kaolin is not readily soluble in weaker acids, dehydrated it is dissolved readily in hydrochloric acid. At this stage, therefore, clay appears to be peculiarly sensitive to chemical agencies, but this condition disappears upon heating the kaolin to higher temperatures. This is also illustrated by the fact that if a thoroughly amorphous clay, like the so-called flint clay, is dehydrated and mixed intimately with slaked lime, it combines with the latter to form a fairly hard cement. If a higher temperature is obtained, this action is not observed.

By means of other reagents clay substance is decomposed similarly. Thus, if heated to a white heat with an excess of lime, as the oxide or carbonate, the kaolin is broken up; the silica of the clay forming a calcium silicate and the alumina an aluminate. On treating it with a very weak acid, like acetic or citric acid, and then digesting it with a weak caustic soda solution, no residue whatever is left. It is possible, therefore, by heating with lime, to convert the clay substance into compounds which are soluble even in dilute acids, although the kaolin itself is practically insoluble in these reagents. The alkaline earths like lime, barium, and strontium, under the influence of heat combine eagerly with the silica of the kaolin, while at the same time the alumina changes its role from that of a base to that of an acid.

It must be borne in mind, therefore, that probably from no other substance can silicate of lime be formed so readily as from clay substance. As to the lime compounds possible of production from pure clay, recent researches have shown that the conditions are quite complex and that relatively small changes in the quantity of lime present will bring about marked differences in the character of the chemical combinations. E. S. Shepherd and G. A. Rankin[1] suggest five possible groups of compounds:

I.	II.	III.	IV.	V.
CaO	$3\ CaO.SiO_2$	$2\ CaO.SiO_2$	$2\ CaO.SiO_2$	$2\ CaO.SiO_2$
$3\ CaO.SiO_2$	$2\ CaO.SiO_2$	$3\ CaO.Al_2O_3$	$5\ CaO.3Al_2O_3$	$2\ CaO.Al_2O_3.SiO_2$
$3\ CaO.Al_2O_3$	$3\ CaO.SiO_2$	$5\ CaO.3Al_2O_3$	$CaO.Al_2O_3$	$CaO.Al_2O_3$

Groups III and IV are thought to represent average conditions. The existence of tricalcium silicate, which by many earlier investigators was considered to be the main cement forming constituent was finally confirmed by Sheperd and Rankin. It was proven, however, that the compound $3\ CaO.SiO_2$ is unstable at its melting temperature. This substance seems "to form by reaction between the solid components but to decompose before the melting temperature is reached," according to the reaction:

$$3\ CaO.SiO_2 = 2\ CaO.SiO_2 + CaO.$$

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[1] Preliminary report on the ternary system CaO-Al_2O_3-SiO_2. A study of the composition of Portland cement clinker. Jour. Industrial and Engineering Chemistry, 3, page 211.

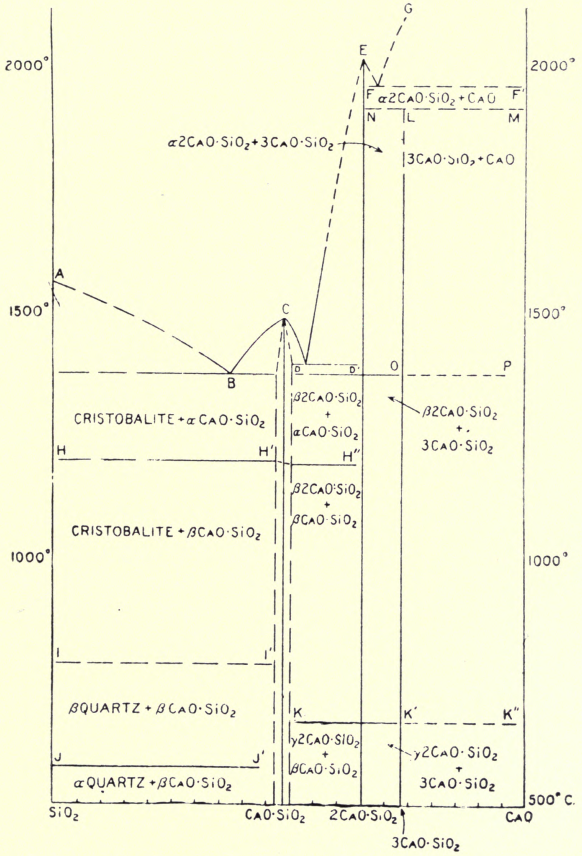
Two of the compounds show polymorphous transformation. Thus, $CaO.SiO_2$ exists in two and $2\ CaO.SiO_2$ in four forms. Of the aluminates, three, $3\ CaO.5\ Al_2O_3$, $5\ CaO.3\ Al_2O_3$, and $3\ CaO.Al_2O_3$ possess one unstable modification. The melting points of the lime-silica compounds are shown in the phase diagram of Plate II, and those of the lime-alumina series are indicated in Plate III.

A number of investigators have produced lime silicates from kaolin by intimately blending and heating it to vitrification. When made up with water the mass proved to possess strong hydraulic properties, i. e., it gave a cement which hardened in water, and showed considerable strength. By heating kaolin to a moderate temperature, considerably below that required for vitrification, a commercial cement of the Roman-cement type has been manufactured in Switzerland and other countries for the last ten years or longer. Owing to its white color, this kaolin cement has found a market for decorative purposes.

It might seem then that in order to produce a lime silicate which is the main constituent of Portland cement, it is necessary only to select a pure clay, thus insuring a smooth reaction. But there are several drawbacks to this proposal. The most important objection is that the vitrified cement obtained in this manner, though possessing good initial strength, has the unfortunate property of increasing in volume as the hydration, or setting, of the cement proceeds. One must distinguish clearly in this respect between the soft Roman cements obtained by burning at low temperature, around 1,000° C., and the vitrified Portland cements. Change in volume after the cement has hardened would be extremely unfortunate and, in fact, would prohibit its practical use. Another drawback is that pure clay substance itself has a high vitrifying or fusing temperature. Its melting point corresponds to about 1,750° C. Likewise, the resulting silicate of lime melts at a comparatively high temperature which is difficult to attain in commercial kilns. It seems obvious then that the Portland cement industry as a whole cannot deal with the pure clays, but must resort to the use of material diluted with other minerals, and especially such as tend to lower the vitrification temperature of the final mixture.

SILICA IN CLAY.

The simplest test of a clay consists in stirring a small amount of it in a glass of water, allowing it to settle a short time, pouring off most of the liquid, and continuing this procedure until the water is practically clear. This reveals in the bottom of the receptacle a layer of variously colored mineral debris of coarse and fine grains. Prominent among these may be seen clear, colorless crystals of considerable hardness which are recognized as sand or quartz grains. These constitute a part of practically every clay, varying from small amounts to the extreme of clay-carrying sands. Quartz, or free silica, is a hard substance which even when very fine grained shows no plasticity. Chemically it reacts at ordinary temperatures with strong bases like caustic potash or soda,



Phase diagram showing melting points of lime-silica compounds

by which it is gradually but slowly dissolved; this reaction being accelerated by using boiling solutions. Only one acid attacks it, namely, hydrofluoric acid, resulting in the vaporization of silicon fluoride gas.

Slaked lime attacks fine-grained quartz at ordinary temperatures forming a silicate of lime, but this process is exceedingly slow. At a somewhat elevated temperature, above the boiling point of water, slaked lime combines with silica far more actively, and this reaction is used in the manufacture of sand-lime brick.

Quartz, when heated alone to temperatures exceeding 800° C., undergoes a marked increase in volume which is ascribed to its transformation into tridymite—another form of crystallization. This change is reversible, though in practice the reversibility only applies in part, so that as a rule quartz is found to have increased in volume on heating. The change from quartz to tridymite corresponds to a volume increase.

When quartz is heated in contact with lime, either as quicklime or as the carbonate, to temperatures exceeding 1,000° C., a chemical reaction sets in and results in the formation of lime silicates which are not necessarily hydraulic. This reaction is shown by the fact that when finely ground quartz mixed with an excess of calcium oxide (quicklime) is heated to these temperatures, the resulting mixture, if treated with strong, hot hydrochloric acid followed by hot sodium carbonate solution, dissolves more or less completely. In other words, while finely ground quartz itself is not soluble in these reagents it has been rendered so by reaction with the lime. This change is also indicated by the formation of gelatinous silicic acid which is observed during the test. This example illustrates what is meant by chemists when they speak of "unlocking" a silicate or quartz, namely, the conversion of the substance insoluble in acids into a form in which it is decomposed and dissolved by acid treatment. A pure clay on being burned with an excess of lime thus becomes completely soluble. In the case of quartz this reaction only follows when it is very fine grained—passing, say, the 200-mesh sieve—and when there is sufficient excess of lime, and provided the temperature has been raised sufficiently high—say, 1,200° C., or more.

By heating an intimate mixture of extremely fine silica and lime, it is possible to produce the various silicates indicated by the phase diagram of Plate II. The metacalcium silicate has a melting point of 1,512° C., the orthocalcium silicate of 2,080°.[1]

An interesting phenomenon is observed on cooling the beta form of the ortho-silicate to the alpha modification. This inversion is accompanied by a decided volume increase and results in the breaking down of the mass to a powder. In cement practice this phenomenon is frequently observed and is called "dusting."

In discussing the function of quartz in cement mixtures it must be remembered constantly that only the finest particles become available for chemical combination, and laboratory tests have shown that the limiting diameter is probably in the neighborhood of 0.0003 inch. In other words, particles larger than this size are too coarse to unite chemically with lime. The practical importance of this fact in attempting to use

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[1] Day and Sheperd, The lime-silica series of minerals: Jour. Am. Chem. Soc., 28, p. p. 1089-1115

clays containing coarse quartz is realized more fully if one assumes, for the sake of illustration, that a clay contains quartz which just passes the 80-mesh sieve, and which represents particles averaging 0.007 inch. On the further assumption that these particles are cubes it appears that each grain of the 80-mesh size must be reduced to, at least, 12 particles of equal size before it becomes useful for chemical combination. This difficulty becomes immensely greater on consideration of coarser grains, such as are found in even fine sands. Some conception may be gained from this illustration of the power required and of the cost of this grinding process.

FELDSPAR IN CLAY.

The alkali-alumina silicate, feldspar, occurs in two principal modifications, the monoclinic and the triclinic. The best known representative of the first group is orthoclase of the percentage composition 16.89 potash, 18.43 alumina, and 64.68 silica. The triclinic group is represented by isomorphous mixtures of albite and anorthite, which are of the compositions, respectively, 11.82 soda, 19.56 alumina, 68.62 silica; and 20.10 lime, 36.82 alumina, and 43.08 silica.

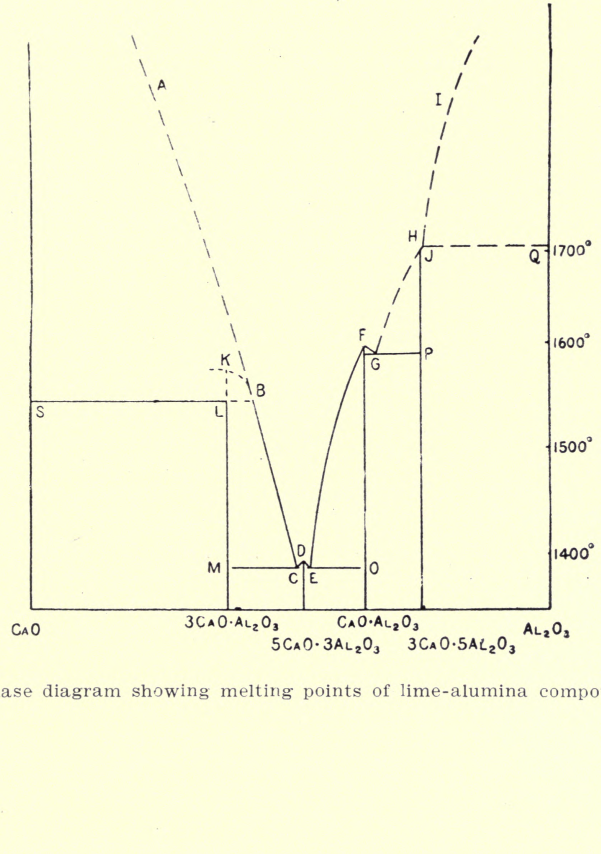
Andesine, labradorite, and oligoclase are mixtures of these two minerals. Owing to the high content of fluxes the feldspars are quite fusible and their silica, being in the combined state, is readily available for chemical union with the lime of cement mixtures. Their presence in clays, therefore, is desirable up to a certain limit at which the alkali content thus introduced becomes too high.

IRON OXIDE IN CLAY.

Two forms of iron oxide must be distinguished—the ferric Fe_2O_3, and the ferrous, FeO. Iron oxide, especially in the form of ferric oxide, is an exceedingly important constituent of cement clays, owing to the fact that it contributes to the vitrification of the clay at a lower temperature, and in this way brings about the chemical combination of the cement mixture at temperatures attainable in the rotary kiln under commercial conditions. In order to be of maximum benefit in this connection, the ferric oxide should be disseminated throughout the clay in the colloidal condition and in a state of extreme subdivision.

The color of this form of oxide is invariably red, causing the clay to appear yellow or reddish.

The ferrous oxide is black and usually does not occur in clay in the free state but is nearly always combined with carbon dioxide to form the carbonate ($Fe\ CO_3$), or it may be present as ferrous silicate. The carbonate when heated loses its carbon dioxide gas and becomes changed to ferrous oxide. The latter is an exceedingly active flux and combines with silica with great eagerness to form a black slag, ferrous silicate. This change is not desirable, however, in the cement reaction since it is liable to produce a less hydraulic silicate, owing to the fact that the ferrous oxide itself takes the place of part of the lime, and thus lowers the amount of silica available for the cement silicates. At the same time it causes mechanical difficulties due to slagging. Ferrous oxide differs



Phase diagram showing melting points of lime-alumina compounds.

from the ferric in being distinctly basic and is more active in this capacity, since one molecule of ferric oxide ($Fe_2 O_3$), is equivalent to two molecules of ferrous oxide ($Fe O$). Ferric oxide is capable of uniting with lime itself and has been clearly shown by Schott, Zulkowski, and others to form compounds analogous to aluminates, which are distinctly hydraulic. These ferrates do not possess the high degree of hydraulicity of the aluminates, and they set much slower. However, as they are considered to be more stable, it has recently been suggested that ferric oxide be introduced to replace most of the alumina in cements intended for use in sea water and for similar purposes where the solvent action of saline solutions comes into play.

The essential difference between ferric and ferrous oxide is in the fact that the former may exercise a dual function—being a base in acid combinations and in acid in basic combinations—the second conditions existing in cements. The ferrous oxide invariably acts as a base.

MICA AND OTHER IRON-BEARING MINERALS IN CLAY.

When a clay is examined by means of the mechanical analysis—that is, worked up thoroughly with water to form a thin slip and passed through a series of sieves—the screens nearly always retain mineral particles which evidently are neither quartz nor feldspar, but show either distinct plate-structure or dark to black color. These minerals are readily identified as mica, which is never absent, or as augite or hornblende. Occasionally black grains of magnetite are also found. Mica, a common, well-known mineral, is a soft substance consisting of parallel flakes which are capable of indefinite subdivision. In composition it varies widely and carries percentages of from 3 to 12 of potash, 0 to 4 soda, 0 to 1.5 ferrous oxide, 0.5 to 9 ferric oxide, 0.5 to 3 magnesia, 28 to 38 alumina, 43 to 52 silica, and from 1 to 6 of chemical water. Although soft, it resists the action of weathering remarkably well, and is therefore present even in clays which have been subject to intense eroding action. Biotite or black mica containing from 10 to 30 of magnesia occurs frequently. Augite and hornblende are likewise silicates of alumina, lime, magnesia, iron, and alkalies and are usually of a darker color.

As to the action of these minerals when heated with lime it may be said that, provided the particles are sufficiently fine, they offer no difficulty in the formation of the basic silicates necessary for the cement reaction, because their silica is in the combined state. Probably mica resists chemical combination longest, since its flakes are extremely thin and easily elude the grinding action of pulverizing machines.

FURTHER ACCESSORY CONSTITUENTS OF CLAY.

Among the numerous substances which go to make up clay may be mentioned iron pyrites ($Fe S_2$), ferrous carbonate ($Fe CO_3$), gypsum ($Ca SO_4 . 2 H_2O$), titanate of iron ($Fe_2 Ti_2 O_3$), dolomite, ($(CaMg) CO_3$), carbonate of lime ($Ca CO_3$), carbon in the form of organic matter, bitumen or graphite, and various other minerals and rock fragments.

For the purposes of the cement manufacturer none of these, with the exception of the carbonate of lime, serves a useful purpose. In fact, the dolomite, pyrites, and gypsum may be considered injurious. The first, since it introduces undesirable magnesia into the cement mixture; the latter two, because their sulphur content may likewise exert a deleterious influence.

Important Physical Qualities of Clays.

It has been shown that clay is a complex rock composed of essential and unessential minerals with functions which have been briefly indicated. Besides the general chemical considerations, however, it is important to regard the physical make-up of clay with respect to four principal points, viz., fineness of grain, hardness, density, and uniformity of the deposit.

Since the importance of fineness of grain has been shown in the preceding paragraphs, it is evidently of primary significance from the commercial standpoint to select a clay which possesses a fine-grained structure and thus requires the minimum cost for grinding. It is evident that a soft, fine-grained material is to be preferred to a hard, rock-like clay, not only on account of the cheapness of grinding, but also by virtue of the more intimate contact established between the grains of clay and the more numerous particles of limestone due to the relatively large area exposed by the soft clay grains.

The hardness of the clay should not be excessive. However, with modern grinding machinery the average shales are reduced without great expense, and this consideration applies only to excessively hard and partially metamorphosed materials similar to slate. This is due to the fact that most hard clays are of very fine grain, and it is not the coarser grinding which is expensive, but the last reduction to the fine, almost microscopic, particles. An illustration of what is meant by this is afforded by a piece of hard, blue shale. Though apparently quite difficult to grind, on placing a piece of it in hot water for some time it will be found to soften and finally to resolve into a plastic mass which passes even the finest sieve. The surface factor, or the superficial area of the total number of grains in unit weight of clay should be as great as possible.

Accordingly, a dense clay is not as desirable as a lighter, fine-grained clay, although this is, to some extent, compensated by the greater weight per unit volume of the resulting cement mixture. In other words, a batch of raw cement made with a dense clay represents a greater weight per cubic foot of kiln space than the same volume of raw mixture prepared from a light, flocculent clay. Since cement is sold by weight, this condition is a factor in favor of the heavier clay.

Uniformity is extremely desirable in a clay deposit for self-evident reasons. A cement plant representing a large outlay of capital is dependent upon the satisfactory character of its raw materials, and it is exceedingly important that the geological formation should assure a reasonable uniformity.

CLASSIFICATION OF CLAYS.

For the purpose of cement manufacture the following practical classification of clays as regards the Illinois deposits can be made:

- Fire clays
  - High grade.
  - Low grade.
- Shales
  - Aluminous.
  - Ferruginous.
  - Siliceous.
  - Calcareous.
  - Carbonaceous.
- Plastic, ferruginous, or calcareous clays
  - Weathered shale.
  - Alluvial
    - Deposited in swift-running water.
    - Deposited in slow-running water.
    - Deposited in still water.
  - Glacial
    - Drift-clay, proper.
    - Re-deposited glacial clay.

FIRE CLAYS.

The term "fire clay" is an indefinite one standing in general for clays which do not fuse excepting at high temperatures. Though no definite limit has ever been set, it may be said that no clay can be called a fire clay of good grade unless it withstands a temperature of approximately 3,000° F., without showing signs of softening. These clays may be white or yellowish in color when burned; a reddish-burning clay may be a fire clay, but the chances are against it. The value of a fire clay can be determined definitely only by a refractory test. The high fire-resisting quality of a clay is due to the absence of fluxes, and to the fact that the composition approaches more or less closely to that of the ideal clay substance ($Al_2 O_3 . 2 Si O_2 . 2 H_2O$). A clay containing much above 46.3 per cent of silica cannot, therefore, be a high-grade fire clay.

For cement making purposes the high-grade fire clays do not come into practical consideration. This is due to the fact that these clays are too high in alumina, and consequently would produce dangerous quick-setting cements. On the other hand, they are so low in fluxes like iron oxide that the vitrification of the clinker would require too high a temperature for practical operating purposes.

The low-grade, or No. 2 fire clays, associated with the coal measures, differ from the high-grade materials in that their composition shows a considerably higher content of silica and of fluxes. This necessarily lowers their softening temperature, although they still burn to a light buff color. These clays are liable to contain concretionary iron sulphide in considerable quantities, which may cause irregular behavior in firing.

As a rule, these materials are very fine grained and quite uniform in composition within reasonably large areas. They are nearly always associated with coal beds, to which they conform very regularly. They are a possible source of raw material for cement manufacture, owing to their fineness of grain, uniformity, and ease of reduction, provided that their silica content is within the limits found advisable, so that the percentage of silica divided by the percentage of alumina is not less than 2.5 and not much more than 3.5. However, where other clays higher in iron are available and otherwise suitable, the more ferruginous ones should be preferred; since the No. 2 fire clays still necessitate a higher vitrification temperature than is needed for the red-burning materials.

SHALES.

Shales differ from clays in that they have been subjected to pressure after deposition in still water, and have obtained a characteristic cleavage and structure. If this is carried further the shale becomes slate. Owing to their origin in still water shales are nearly always of extremely fine grain and quite uniform in composition over reasonably large areas. The term shale, however, does not stand for any given chemical composition. Shales may be high or low in fluxes—of high or low refractoriness. Thus, there are shales so high in alumina that they may be considered fire clays, in which case they become unfit for cement-making purposes, for the same reason that other fire clays are unsuitable.

The ferruginous shales, high in ferric oxide, are very common and are used in the clay industry for various purposes, such as the manufacture of paving brick. There is no reason why shale of this character could not be used for cement manufacture. A well-known material of this type is the Galesburg shale of the following composition:

Analysis of Galesburg shale.

Silica (SiO_2)	63.62
Alumina (Al_2O_3)	16.31
Ferric oxide (Fe_2O_3)	6.22
Ferrous oxide (FeO)	2.88
Titanium oxide (TiO_2)	0.96
Lime (CaO)	0.63
Magnesia (MgO)	1.44
Potash (K_2O)	2.60
Soda (Na_2O)	1.50
Loss on ignition	6.26
Moisture	0.38

Similarly, shales may be high in silica, lime, or carbon. The last-named are usually black in color and contain bitumen which volatilizes readily and burns like a rich gas. In shales of this type the iron is usually present as ferrous carbonate or ferrous sulphide.

For cement-making purposes only the shales too high in silica are seriously objectionable, although the carbonaceous shales may cause some inconvenience in burning, and also difficulty in grinding.

As a class, shales are desirable for cement manufacture provided their chemical composition is within the allowable limits.

PLASTIC CLAYS.

Weathered shales—As the shales are weathered by atmospheric agencies they gradually lose their characteristic structure and again become clays, retaining, of course, the same chemical composition except that all of the iron and sulphur compounds become oxidized. In other words, all ferrous oxide, as well as the ferrous carbonate, is changed to ferric oxide, and all sulphides become sulphates. As a result the hard mass is converted into a soft plastic clay, which if suitable in chemical composition and fineness of grain is rendered more valuable by this metamorphism, since its softness makes it easy and cheap to grind. In addition, the uniformity of the composition, a property peculiar to shales, makes a clay of this type an exceedingly valuable cement material.

Alluvial clays—The comparatively fine rock-matter deposited by water is called alluvium. Since all bodies of water carry clay which is deposited under various conditions, and since the size of the particles allowed to settle depends upon the velocity of the current, it follows that the swifter the flow the coarser will be the matter deposited. This naturally leads to a classification depending upon the rapidity of flow of the water which has deposited the clay. The body of water may still be in existence or only its old bed may be traced.

It is evident that alluvial clays prospected for cement-making purposes should be found in the beds of slowly moving bodies of considerable size, since only these conditions insure fineness of grain and uniformity of composition sufficient for practical operations. In examination of clays of this type, a careful study should be made of the conditions which governed the deposition of the clay, as well as of the extent of the bed; since many alluvial clays are extremely irregular in composition and show layers of clay alternating with streaks of sand and gravel. There are fine-grained, alluvial-clay deposits of considerable magnitude, but, as has been said, a thorough investigation of the extent of such a bed should be made by means of borings before risking an investment. The most promising deposits of this kind are offered by those old lake beds in which the conditions of sedimentation have been such that only the finest particles have been laid down. In this way clays excellently suited for cement making have been deposited.

Glacial clays—A large part of Illinois is covered by glacial drift—a conglomerate mixture of native clay, shale, sandstone, limestone, and various other rocks, mostly of igneous origin, which have been brought from the north by the sheet of ice which once covered much of the State. As a class the glacial clays are entirely unsuited for the manufacture of Portland cement, and any attempt to make use of them usually ends disastrously. These clays may be dismissed by stating that they are not promising except where washed out from the admixed rock debris and deposited again in lake beds and river bottoms. Such secondary material becomes available, locally, if sufficiently fine grained and of the proper silica-alumina ratio. These deposits naturally require careful exploration.

LOESS, SANDSTONE AND SAND FOR MIXTURE WITH CLAY.

In dealing with aluminous clays, with too low a silica-alumina ratio, the conditions might make it advisable to correct the proportions by the addition of a fine-grained siliceous material. In this connection might be considered the loess clays of western and southern Illinois, which are commonly supposed by geologists to be wind deposits. They are very high in silica, and frequently of great fineness. In attempting to use a No. 2 fire clay, too high in alumina for cement manufacture, for instance, a mixture might be made with loess to establish the proper ratio. Similarly, fine-grained sandstone, or still better, the extremely fine, white, silica occurring in large amounts in southern Illinois could be utilized. The objection to the use of loess clay would be its irregularity in composition and size of grain; but this would not apply in the case of fine-grained sandstones and amorphous silica deposits. In any case, the amount of siliceous addition should be as low as possible in order to keep down the cost of such a mixture; for at best it would be but a necessary evil.

LIMESTONE MATERIALS.

CHARACTER AND WORKING BEHAVIOR.

The limestone of Illinois is its principal source of lime for the manufacture of Portland cement, since practically no marl deposits exist. Geologically, limestone is the result of the water deposition of the carbonate of lime—more or less admixed with fine-grained clay and sand, according to the conditions of sedimentation. The content of magnesium carbonate may be so large that it approaches 45 per cent of the stone; in which case there exists either an isomorphous double compound, $CaCO_3.MgCO_3$, known as "dolomite"—or a mixture of dolomite and calcite in which the magnesia content diminishes with the decrease in dolomite.

A strong resemblance exists, in many chemical respects, between the calcium and magnesium compounds. Both carbonates when heated lose their carbon dioxide and become oxides; though the dissociation of magnesium carbonate takes place at a lower temperature. Both oxides on being brought in contact with water slake and form hydrates; the magnesia, however, reacting more sluggishly, and with the evolution of less heat. Again, both oxides, if intimately combined with clay in the proportion obtained in the average Portland cement—about 3 molecular equivalents of lime or of magnesia to 1 of silica, 0.2 of alumina, and 0.06 of ferric oxide—and burned to vitrification result in hydraulic cements. When ground to a powder and mixed with water both hydrate and harden. But, while the lime-cement will set with considerable rapidity, the magnesia compound will harden slowly.

In making up a Portland cement with dolomite it is evident that the silica must be distributed between the two bases so that the magnesia replaces part of the lime of the regular cement. Whether this mutual replacement during the process of vitrification takes place smoothly is not known, but it would seem from the study of the fusion curves of the independent calcium and magnesium silicates that the two bases vary considerably in formation behavior.

According to work done in the geophysical laboratory of the Carnegie Institute, four crystalline modifications of magnesium metasilicate ($Mg\ SiO_3$) exist. One stable compound of a double lime-magnesium silicate ($CaO\ MgO\ SiO_2$) has been found which melts at 1,380° C. and has a specific gravity of 3.275.

Neglecting entirely the differences in fusion behavior and assuming that the replacement of the lime by magnesia results in normal silicates, a difficulty is bound to arise on hydration owing to the different rate of hydration of the magnesium and calcium compounds. Just as the calcium oxide combines with water so much more eagerly and rapidly than the magnesium oxide, so the calcium silicates and aluminates of a vitrified cement hydrate more quickly than the corresponding magnesia compounds. But hydration of anhydrous substances invariably brings about volume changes, as is illustrated by the slaking of lime. One unit weight of pure quicklime ($Ca\ O$) corresponds to 0.314 units of volume. On slaking by the addition of water this weight is increased to 1.75 units of weight and the volume from 0.314 to 0.833 volumes, which is equivalent to 2.62 times the original bulk of the quicklime. Although the volume changes pertaining to the basic silicates are not nearly of this magnitude, yet the fact remains that they take place.

If both lime and magnesia silicates exist together in the cement, and the lime silicate hydrates and sets faster than the magnesium compound, it is evident that the volume change of the latter must take place after the calcium silicates have done their share towards hardening the cement. This, therefore, causes strains within the cement which are likely to bring about cracking or the entire destruction of the cement. For this reason it is advisable to keep the magnesia content as low as possible.

Pure carbonate of lime ($Ca\ CO_3$) consists of 56 parts of calcium oxide (CaO) and 44 parts of carbon dioxide (CO_2). On being heated to a temperature of about 900° C. the compound dissociates and the gas escapes. The harder, the more crystalline, and the denser the carbonate of lime is, the higher is the temperature required for dissociation. Herzfeld has found, however, that 1,040° C., is sufficient to decompose all of a large number of limestones. The presence of impurities like silica, alumina, and iron oxide accelerates the decomposition, and for this reason impure limestones are easily overburned; that is, the lime combines chemically with the impurities to a more or less dense mass which does not slake readily, but becomes inert, so far as the ordinary uses of lime are concerned.

The dissociation of lime carbonate at atmospheric pressure becomes purely a matter of temperature, and it has been found by Johnston that 898° C., is the minimum temperature at which pure $Ca\ CO_3$ can be burned at atmospheric pressure in the absence of steam. In the presence of superheated steam the decomposition takes place at a lower temperature. In the nature of the case the dissociation of carbonate of lime,

$$Ca\ CO_3 + \text{heat} = Ca\ O + CO_2.$$

is a heat consuming one and might be written:

$$Ca\ CO_3 + 437.4\ \text{cals.} = Ca\ O + CO_2.$$

One gram of calcium carbonate, therefore, requires 437.4 gram calories for its decomposition; or 100 pounds of the carbonate would theoretically need the total heat of 6 pounds of good-grade coal. Practically, the heat consumption is about four times as large. The reaction is a reversible one; for by conducting carbon dioxide gas over quicklime, previously heated to redness, the union resulting in the formation of the carbonate takes place with the evolution of the same amount of heat as was previously required for dissociation. The specific gravity of the calcium oxide varies from 3.27 to 3.40.

On being brought in contact with water, either as steam or in the liquid form, calcium oxide changes to the hydroxide according to the reaction:

$$CaO+H_2O=Ca(OH)_2+15{,}100 \text{ cals.}$$

Here is represented the familiar operation of slaking, and every gram of the quicklime releases 269.6 gram calories. At the same time the reaction brings about a large increase in volume, since the specific gravity of the hydrate is approximately 2.1.

The chemical union between the calcium carbonate and the silicates in the formation of Portland cement takes place only if both materials are ground very fine, since it is evident that chemical action can be complete only when sufficient contact area is exposed. The finer the grains of the materials the more readily does the reaction proceed. Again, it is true that crystalline calcium carbonate reacts more reluctantly than the amorphous form; and this is equally true of the silica of clay. As to the composition of the limestone, it is by no means necessary that it be pure —that is, high in lime and low in silica. In fact, the contrary is desirable, provided the silica and alumina are present in a ratio within the allowable limits. Owing to the fact that the silica and alumina in limestone are usually present in a state of fine subdivision, it is clear that if the chief cement-making constituents can thus be obtained in a state of intimate natural admixture, blended together finer than is possible for human agencies to accomplish, a great deal has been gained. The ideal condition naturally is that in which the lime, silica, alumina, and ferric oxide are present in the stone in the proportion needed for a Portland cement; in which case, of course, no other addition is necessary. This condition is actually approached in the cement rock of the Lehigh Valley, Pennsylvania, where it is the basis of a large cement industry. The purity of the limestone, therefore, in the light of the above consideration, is of no importance.

Classification of Limestone.

A technical classification of highly calcareous limestones could be based upon chemical composition or physical structure. Considering the chemical composition only from the standpoint of suitability for the purpose of cement manufacture, a classification on this basis is unnecessary; and for the present purpose it suffices to arrange the lime materials according to their structure, as follows:

1. Coarsely crystalline stone. Pure, i. e., very low in silica and clay matter. Composed of large, well-defined crystals of calcite and aragonite. Coral rock and other mineral remains may be present.
2. Dense, crystalline granular stone. Pure. Differs from first group only in structure and may be recrystallized. This type represents the most common limestones. In this group, however, are also included the marbles—metamorphosed limestones composed of calcite grains of great uniformity.

3. Dense, dull, but hard stone. Impure. In these rocks either the content of clay, carbonaceous matter, or fine silica, or of all of these is so high that the granular limestone structure is no longer prominent, though the hardness is but slightly impaired. Cement rock.

4. Shale rock. Stone of shale-like structure in which the clay content is high enough to cause the limestone structure to disappear entirely. Such materials are on the boundary line between clayey limestone and calcareous clays. The hardness is about that of shale.

5. Chalk. Fine rock flour, derived from the remains of foraminifera and other marine organisms; soft; usually pure.

6. Marls. Soft, amorphous, calcium carbonate, varying through all grades of purity from nearly pure carbonate to calcareous clay. Travertine, though of a different origin, may be included in this group from the technical standpoint. Marl deposits constitute the bottoms of glacial lakes in Michigan, Indiana, Ohio and other states. Frequently shells are present in sufficient quantities to cause serious annoyance in the manufacture of cement. Formerly, owing to its extremely fine structure, marl was considered the ideal raw material for cement making, but owing to the varying depth of the deposits, the fluctuations in composition, low specific gravity, and high water-content, its use is no longer considered so desirable.

From the standpoint of the manufacturer, the materials of groups 3 and 4 are best suited for his purposes since the required clay matter occurs in the stone itself, either wholly or in part, and in a most desirable condition, being finely disseminated and blended with the carbonate of lime. In the absence of such material the pure crystalline or granular limestone is desirable, in which case, however, the selection of a suitable clay becomes an important matter.

THE EXAMINATION OF CEMENT MATERIALS.

Field Investigation.

In order to determine the suitability of certain raw materials for the manufacture of Portland cement the question of chemical and physical tests becomes a significant one. In this connection the importance of obtaining proper samples, and of thoroughly examining a property should be emphasized. Only too often this important matter is greatly neglected in spite of the heavy investment involved in the erection of a cement plant. This is especially true as regards clay deposits; with the result that the efficiency of the mill is sometimes seriously handicapped by a location making necessary the use of an unsuitable clay. In addition, in the use of certain clays there is constant danger of producing an inferior cement. The prospecting of a cement property should be placed in the hands of an expert, and should not be left to the tender mercies of the professional promoter.

The first step in the examination of both the limestone and the clay is the chemical analysis. In this connection it is not thought advisable to consider here the general analytical methods employed, but to restrict the discussion to special methods and to the results of the analysis. For laboratory methods such a work as "Portland Cement," by R. K. Meade, may be consulted.

CLAY ANALYSIS.

The chemical composition of the clays may be considered in regard to the following standpoints:

1. The ratio between the percentage of silica and alumina.

The content of:

2. Magnesia.
3. Ferric oxide.
4. Alkalies.
5. Sulphur.
6. Inert mineral matter.

1. *Silica-alumina ratio*—The ratio between the silica and alumina content of clays as has already been indicated is an important factor. Too much alumina will result in a cement which sets too rapidly and is liable to be inconstant in volume; while, on the other hand, a clay which is too silicious will give a cement which is too slow setting for commercial purposes or which, unless the free silica is very fine grained, will cause the cost of raw grinding to be excessively high. An examination shows that 20 American Portland cements have an average silica and alumina ratio, i. e., the percentage of silica divided by the percentage of alumina, approaching 2.9, while several hundred German cements average 2.78.

Although, of course, this ratio expresses the silica-alumina relation in the mixture of the clay and lime material in cements, it furnishes some clue as to the desirable proportion in the clay. It is evident that the allowable ratio depends also upon the composition of the limestone. In connection with a siliceous stone the clay may have a much lower proportion of silica to alumina than in the case of a pure or more aluminous limestone, since the ultimate silica-alumina ratio is evidently governed by the following relation:

$$\frac{a_1 + a_2 x}{b_1 + b_2 x} = C$$

where a_1=per cent of silica in clay.
a_2=per cent of silica in limestone.
b_1=per cent of alumina in clay.
b_2=per cent of alumina in limestone.
x =parts of limestone to 1 part by weight of clay.
c =silica-alumina ratio of resulting cement=2.5 to 3.50.

It is therefore impossible to state whether the silica-alumina ratio may be kept within the desirable limits until the analyses of both the clay and the limestone are known. For satisfactory results it is, of course, best when the value x—the parts of stone to 1 part of clay—results in a silica-alumina ratio which is within the allowable limits and which might be taken to be 2.50 and 3.50. Since the limestone analysis is usually obtained first, it is necessary that the clay to be selected should conform in composition to these limits of the silica-alumina ratio. In case a practically pure limestone is used the clay itself should come within these values.

2. *Magnesia content*—The amount of magnesia permissible in a clay naturally depends upon the magnesia content of the limestone. The amount permissible in Portland cement is usually taken as 3 per cent. This is an arbitrary limit for which, perhaps, there is not sufficient justification since many cements with considerably more magnesia have given excellent results, both in practical work and in laboratory tests. The average magnesia content of 14 American Portland cements was found to be 2.05 per cent; of several hundred German cement samples, 1.63 per cent. Since the consensus of opinion is against the presence of more than 4 per cent of this compound, commercial reasons alone dictate, therefore, that a clay should not contribute more magnesia than would bring its content above 3 per cent in the finished cement.

3. *Ferric oxide content*—The iron oxide is not usually taken into account except when the clay is too low in iron. A certain amount of ferric oxide is necessary in clays for the purpose of promoting the vitrification of cements, as has been shown in previous statements. It has, nevertheless, an important function to perform, although, in itself, it is not considered to contribute much towards the production of hydraulicity. Its amount in the clay should be such that with the required amount of stone it does not produce a cement containing less than 2 per cent of ferric oxide. A higher content in the clay, corresponding to as much as 6 or 8 per cent, is not objectionable.

4. *Content of alkalies*—The presence of alkalies in the form of feldspar cannot be considered objectionable, especially since in the red-burning clays this mineral hardly ever occurs in excessive quantities. Feldspar is a flux which is valuable in reducing the burning temperature, its effect being gradual, and in direct proportion to the amount present. Its fluxing effect begins at low temperatures, about 1,070° C., and continues more vigorously as the temperature rises. Combined with ferric oxide and some lime, feldspar forms a very easily melting silicate mixture,[1] which, by solution, enriches itself from the other constituents of the cement as the temperature rises, thus being essential in bringing about the vitrification of the whole mass. Feldspar is able to dissolve from 2.5 to 3.5 per cent of alumina; 13 to 14 per cent of clay substance; and from 60 to 70 per cent of quartz.[2]

5. *Sulphur content*—Sulphur is objectionable; and since some shales and No. 2 fire clays contain considerable amounts of pyrites and other sulphur combinations it is important to pay some attention to this feature. In addition, the cement absorbs more or less sulphur from the coal, so that the amount allowable in clay must be decidedly less than the maximum permissible in the cement. From careful investigations carried on by the German Association of Portland Cement Manufacturers, it appears that a content of 3 per cent of total SO_3 in the finished cement should never be exceeded. This includes the sulphur brought in by the gypsum which is added in the grinding of the clinker.

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[1] Bleininger, A. V., Trans. Am. Ceram. Soc., Vol. 10.

[2] Plenske, Sprechsaal, 1908, Nos. 19-24.

Assuming that 2 per cent of raw gypsum is introduced in this way, the maximum amount of SO_3 permissible in the cement proper is not more than 2 per cent.

6. *"Inert mineral content"*—By this term is meant the percentage by weight of the residue which remains behind, after the unground clay is intimately mixed with eight times its weight of calcium carbonate, heated to a bright-red heat, cooled, treated successively with hot hydrochloric acid and sodium carbonate solutions, and the residue finally washed thoroughly with a weak acid solution and ignited. The clay in this process is first mixed with a large amount of water, boiled, and, if necessary, deflocculated by shaking thoroughly until the granular matter has separated from the flocculent portion; the whole being passed through a 40-mesh sieve. The clay suspension is then evaporated to dryness, intimately mixed, and a sample taken for calcination with the calcium carbonate. This treatment closely imitates the burning of Portland cement, and it is evident that all the constituents of the clay which can unite with the lime will do so and the inert matter will remain uncombined and, hence, insoluble in acid and alkali. It is evident that the principal part of the inert material consists of quartz which is too coarse to be available for chemical combination, though a portion may consist of silicates unavailable for the same reason. In the case of very fine-grained clays, such as shales, redeposited alluvial and glacial clays of the lacustrine type, and No. 2 fire clays, practically no residue is found. In the case of the ordinary surface clays this residue may be very high.

The practical meaning of this test is obvious. If nearly all of the unground clay is thus brought in solution the cost of raw grinding, as far as the clay is concerned, will be at the minimum, and a material of this type, provided its chemical composition is satisfactory otherwise, would be exceedingly desirable. On the other hand, any considerable amount of inert residue must be reduced by grinding until it is fine enough to enter into reaction with the lime. This point is especially important as regards plastic clays, as it may even mean the success or failure of the plant. When the fact is considered that coarse material not only increases the cost of grinding but also that it involves the use of higher temperatures in burning, since it is commercially impossible to reduce it to the desirable fineness, the importance of this factor becomes manifest. If, therefore, a plant is able to produce only 450 barrels of cement per kiln in 24 hours, when it might approach a capacity of 600 barrels, the question of cost assumes a serious aspect. Where there is a possible choice between clays, the one showing the smallest residue on calcination with lime should be selected invariably.

LIMESTONE ANALYSIS.

The statements regarding the clay analysis hold practically for the limestone, and may be summarized as follows:

1. The lime-carrying material should be fine-grained and uniform in composition and structure (free from concretions).

2. Its magnesia should be low enough so that a content of 3 per cent of magnesium oxide is not exceeded in the cement.

3. Its alumina content should not be high enough to disturb the proper silica-alumina ratio in the cement.

4. It should be low in sulphur and free from pyrites.

The most important question referring to the chemical composition of the lime-carrying material is that of the magnesia content; for it is evident that if more magnesia could be allowed the cement resources would be greatly increased.

While the well-known experiments of Dyckerhoff have given evidence that the magnesia content is deleterious, other experimentors have shown that this is not the case if the magnesia is calculated to replace an equivalent amount of lime. This view is advocated by Von Blaese, Mayer, Kawalewsky, Golinelli, Campbell and White, and others. The last named investigators[1] probably offer the soundest view upon this subject, which is quoted as follows:

"The effect of magnesia, like that of lime, depends less upon its total amount than upon the form in which it exists. Combined magnesia, like silica lime, has no injurious effect in Portland cement. Magnesia combined with silica and alumina forms a hydraulic cement which is safe but, as compared with Portland cement, is too weak to be of any commercial value. Free magnesia has no appreciable effect in cement used above ground where it is continuously dry. If the cement is wet for a part or the whole of the time, the free magnesia will hydrate very slowly and cause expansion. Even where the cement is continuously in water the expansion due to free magnesia is not appreciable until after two months, and only becomes distinctly evident after a year. The hydration seems to be only well under headway at the end of the first year, and expansion continues at an increasingly rapid rate for at least five years, and probably longer. Ageing does not seem to diminish the deleterious effect of free magnesia in cement. This is to be expected, since the rate of hydration of hard-burnt magnesia in air is almost imperceptibly slow. * * * Increased percentage of *free* magnesia causes cumulatively greater expansion until, with 3 per cent of free magnesia, the expansion is too great to be at all safe."

As regards the limestone structure, it is obvious that the finer grained and softer the material is, the better it is for cement making.

PHYSICAL TESTS.

Physical tests of the raw materials deal principally with the fineness of grain of the clays, and are useful mostly in the selection of clays prior to the plant installation. The importance of fineness has already been pointed out sufficiently.

There are several methods available for the purpose of the so-called mechanical analysis; depending upon separation by sieves, by sedimentation, elutriation, and centrifugal action. One method commonly used in the ceramic industries is based on the use of the so-called Schulz appara-

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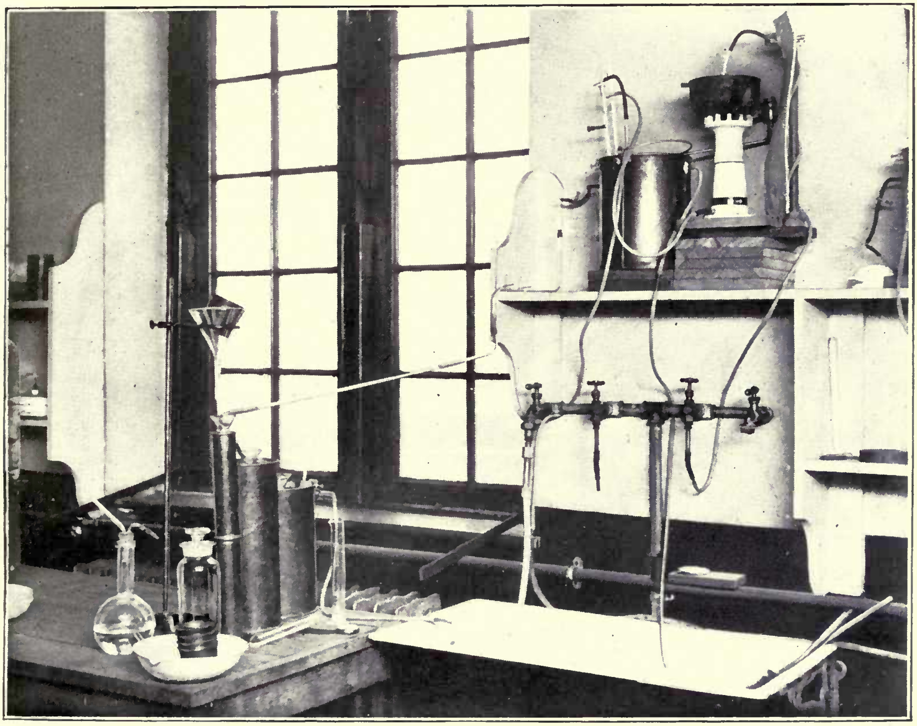
[1] Jour. Amer. Chem. Soc., 28, No. 10.

tus, a device which effects separation by elutriation (Pl. IV). It consists of three tin-lined copper cans, 2, 5, and 6 15/16 inches in diameter, respectively. The vessels are provided with conical bottoms, and water is passed through the series of three cans, flowing first into the narrowest one through a glass thistle-tube of the next can. The flow and the temperature of the water should be kept constant. The former is accomplished by drawing the liquid from a vessel of constant level at the rate of 176 c. c. per minute; the latter, by the use of a heating coil and an automatic thermostat. For practical work the latter feature is not necessary. Since the volume of water per unit of time is constant it is evident that the velocity of the current must be greatest in the first, and least in the last can. The particles deposited in the first can, therefore, are the largest ones, corresponding to an average size of 0.0577 mm., those of the second to 0.0354 mm., and of the third to 0.0167 mm., while the average size of the overflow material is about 0.005 mm.

The mechanical separation is carried out with a 50-gram sample of clay. This amount is first placed in a large bottle with considerable water, to which some caustic soda or sodium oxalate has been added for deflocculation. The receptacle is then mechanically shaken for two hours. The amount of reagent required to bring about deflocculation may be determined by placing a clay sample of about 5 grams in a 100-cc., stoppered graduate, adding caustic soda, which is the more common reagent, in amounts varying from 0.1 to 2 per cent of the weight of the dry clay, shaking for one hour, and noting the amount of sediment formed on settling, as well as the degree of turbidity. The least amount of granular sediment corresponds to maximum deflocculation (Pl. V).

The thin, clay-slip is then poured through a set of small conical sieves, which may be telescoped together and arranged in the order of the sizes of mesh as follows: 20, 40, 60, 80, 100, 120 and 150. The sediments remaining on the sieves are washed thoroughly free from finer material. The sieves are then dried and re-weighed so as to ascertain the weights of the residues. The liquid which has passed through the sieves is then washed into can No. 1, and the flow of water maintained with half the velocity for about the first two hours. The flow is then adjusted to the standard velocity and the apparatus left to complete the elutriation. This stage is noted by the clear appearance of the water in the third can. It is then necessary to draw off the water by means of a syphon down to the conical part of the cans, to wash out the residues, and to evaporate them to dryness for weighing. Thus are found the weights of the sieve and can residues, and, by difference, the amount of material carried off by the overflow.



Schulz elutriating apparatus.

If it is desired to express the fineness of a clay by a single numerical expression it is necessary to know the average sizes of grain of each sediment as well as of the overflow. These values, based on actual measurements upon clays, have been found to be as follows:

Fineness of clay particles.

Mesh of sieve.	Average diameter of grains, mm.
40	0.2170
80	0.1850
100	0.1500
120	0.1275
150	0.0950
200	0.0775
Can No.—	
1	0.0577
2	0.0354
3	0.0167
Overflow	0.0050

The fineness factor is then calculated by dividing the percentage weight of each residue and of the overflow material by the average diameter of the grains, and adding up the quotients obtained. Such a surface factor is useful in expressing not only the fineness of grain of clays, but also of the ground raw mixtures, thus making it possible to give a valuation of the grinding work done upon the materials. Even though the average grain sizes given may not be the same for all materials owing to variations in specific gravity, yet the numerical expression enables one to make comparisons between similar substances.

Summarizing, the chemical and physical tests of cement materials include:

1. Chemical analysis of clay and limestone.
2. Heating tests of clay mixed with carbonate of lime; and determination of the residue insoluble in hydrochloric acid and sodium carbonate solutions.
3. Mechanical separation of clay into certain arbitrary sizes capable of convenient differentiation.

THE EFFECT OF HEAT UPON THE CEMENT MIXTURE.

In the burning of an intimate mixture of limestone and clay to cement, the clay base and the carbonate of lime undergo a series of reactions, which begin with the expulsion of the chemical water from the clay at about 700° C. and the dissociation of the calcium carbonate at approximately 900° C. At the latter temperature it is quite probable that the lime replaces the chemical water of the clay, forming $Al_2O_3.2\ SiO_2.2\ CaO$. At about 1,000° C. the lime combines with the fine-grained free silica leaving, however, much free lime in excess. The mass is now porous, and when worked up with water takes up the latter eagerly by capillary attraction, so that hydration takes place readily.

The material at this stage, therefore, is the equivalent of natural cement, and sets rapidly. As the temperature rises to 1,100° C. the fluxing constituents, especially the ferric oxide, begin to act—thus consolidating the mass—and more free silica is taken up. At about 1,250° C. this action proceeds more vigorously, the mass becomes harder and if allowed to cool would in many cases go down to dust, owing to the formation of the unstable form of the orthocalcium silicate. At from 1,350° to 1,500° C., according to the content of lime, the amount of iron and other fluxes, the fineness of grinding, etc., vitrification takes place rapidly under exothermic conditions. This process may be explained by supposing the fusion of an iron-alumina-alkali-calcium silicate such as would be produced by the heating of a mixture of ferric oxide, clay, feldspar, and calcite, which dissolves more and more lime until the orthosilicate is formed, and some of the calcium oxide is left in solution. Like all calcareous bodies, such a mixture fuses with great rapidity, thus accounting for the short time required for the operation. The amount of heat evolved in the formation of the hydraulic modification of the calcium orthosilicate, which seems to be the compound produced, is not known with any degree of accuracy.

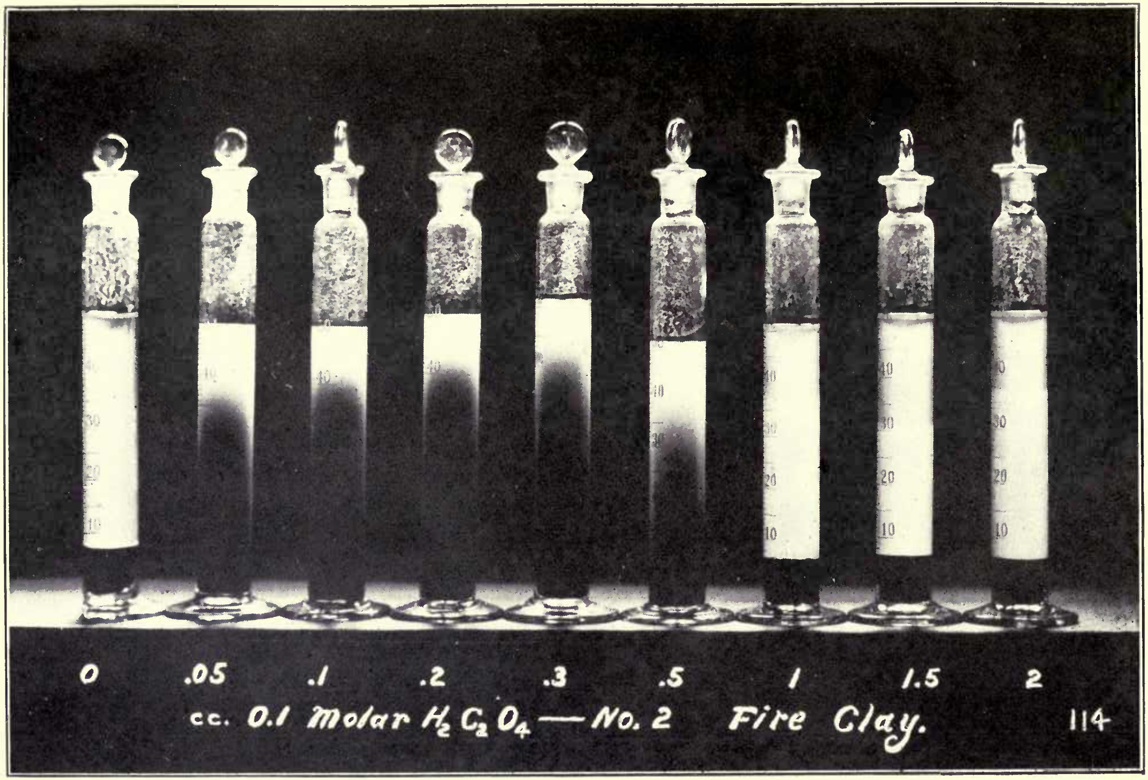
It is evident that the reactions producing the cementing compounds $3\ CaO.\ SiO_2$ and $3\ CaO.\ Al_2O_3$ will more closely approach equilibrium conditions, the finer the mixture has been ground. Insufficient raw grinding results in an undissolved residue, which is detected by treating the ground clinker with hydrochloric acid, and which is usually found to be quartz.

SETTING AND HARDENING OF CEMENT.

When Portland cement is made up with water it sets and begins to harden. The exact mechanism of the hardening does not appear to be known at the present time. In a general way it is presumed that the basic calcium silicate is decomposed, setting free lime hydrate, probably forming a monocalcium silicate and some colloidal products.

Dr. Michaelis, Sr., in his highly interesting and instructive work, considers the colloidal end-products of the hydration to be the important cementing factor, and assumes that these gradually become "set" and harden. A certain amount of water, approximately 14 per cent of the hardened cement, becomes a fixed constituent which is expelled only by heating the cement to red heat.

The facts known relative to the hardening process thus seem to indicate that the dicalcium silicate and the calcium aluminate and ferrate on the addition of water break up to simpler compounds, part of which may assume the form known as "gel" in colloidal chemistry. These colloidal, hydrous substances may again interact with each other to form compounds similar to the zeolites, or they may harden simply by their loss of water.



Deflocculation of clays in water.

CHAPTER III—THE MANUFACTURE OF PORTLAND CEMENT.

(By A. V. Bleininger.)

Consideration of the manufacture of Portland cement includes the following headings:

Composition of the cement mixture.
Winning the raw materials.
Raw grinding.
Burning.
Clinker grinding and storage.

COMPOSITION OF THE MIXTURE.

After preliminary tests have shown the suitability of a clay and a calcareous material, say a limestone, the first step in the manufacture of cement is the calculation of the proper mixture. Various investigators have proposed different chemical formulae based upon extensive experimental studies for the calculation of the cement composition. Thus, Le Chatelier[1] proposed the formula $x\ (3\ CaO.\ SiO_2)+y\ (3\ CaO.\ Al_2O_3)$ based upon the existence of a tricalcium silicate. S. B. and W. B. Newberry[2] suggested a change in the Le Chatelier formula to $x\ (3\ CaO.\ SiO_2)+y\ (2\ CaO.\ Al_2O_3)$. In these expressions the coefficients x and y represent the molecular equivalents of silica and alumina respectively, and hence it follows that the lime content of the mixture to be produced is proportional to the silica and alumina content of clays. Besides the Le Chatelier formula a number of others have been proposed on a more or less empirical basis such as that of Meyer: $x\ (3\ CaO)\ SiO_2+y\ (n\ CaO)\ SiO_2\ R_2O_3$, in which the value of $n = 3$ to 4. A resumé of the various theories proposed by different workers will be found in Bulletin 3, Fourth Series, Ohio Geological Survey. A simple method of calculation, employed very generally in Europe, depends on the so-called hydraulic modulus which may be stated as follows:

$$\frac{\text{Per cent calcium oxide}}{\text{Per cent silica}+\text{per cent alumina}+\text{per cent ferric oxide}}=2.$$

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[1] Recherches experimentales sur la constitution des mortiers hydrauligues: Annales des Mines, 1887

[2] Jour. Soc. Chem. Ind: Vol. 16, No. 11.

This is equivalent to saying that the content of calcium oxide should be twice as great as the sum of the percentages of silica, alumina, and ferric oxide. The permissible variations range from 1.8 to 2.2.

All of these formulæ neglect the ratio of silica to alumina, the amount of fluxing constituents, such as ferric oxide, alkalies, etc., and, necessarily, the degree of fineness of the mixture. As a result, while they may serve for the calculation of the cement mixture they cannot be relied upon to furnish the best proportion for each set of conditions, owing to the variety of factors involved. Nor is it possible with our present knowledge of the subject to derive any suitable general formulæ. As a consequence, the fixing of the best proportion of clay to lime material is more or less of an empirical procedure.

Thus, we might use the Le Chatelier-Newberry formula to obtain the maximum proportion of lime to silica and alumina, and by systematic reductions and trial burns obtain cement of the proper quality. The calculation of the cement mixture might be illustrated as follows, given a clay and limestone of the following compositions:

Analyses assumed for calculations.

	Clay.	Limestone.
Silica	63.40	1.20
Alumina	21.50	0.50
Ferric oxide	5.60	0.30
Lime	0.90	53.00
Magnesia		1.05
Loss on ignition	7.10	42.10

Since in the formula $x\ (3\ Ca\ O.\ Si\ O_2)+y\ (2\ Ca\ O.\ Al_2\ O_3)$ the lime-silica and the lime-alumina ratios are 2.8: 1 and 1 :1 respectively, it is obvious that the silica of the clay requires $63.4\times2.8=177.52$ parts of lime and $21.5\times1.1=23.65$ parts of lime. This gives a total of 201.17 parts of lime, from which must be deducted the per cent of lime already present in the clay or 0.9 per cent. This results in $201.17-0.9=200.27$ parts of lime to be furnished by the stone.

Since the latter contains some silica and alumina it is evident that these must have their share of lime before any of it becomes available for the clay. Thus, from the 53.0 per cent of lime there must be deducted $(2.8\times1.2)+(1.1\times0.5)=3.91$ per cent. This leaves $53.00-3.91=49.09$ parts of Ca O available. With every part of clay, therefore, must be mixed $200.3\div49.1=4.08$ parts of limestone or 400 pounds of stone to every 100 pounds of clay. This amount of lime, hence, is the maximum under the assumption of extremely fine grinding and ideal conditions. It would correspond to 65.96 per cent of Ca O in the finished cement. If the lime content of the unground cement clinker is assumed to be on the average 63.0 per cent, as is frequently the case in practice, it is evident that the Le Chatelier formula might be replaced by a simple arithmetical computation.

This calculation is based upon an average lime content in Portland cement clinkers of 63 per cent. Applying it to the above case and computing the lime in terms of the weight after ignition, both in the case of the clay, as well as of the limestone, one would have the simple equations:

$$\frac{0.9x}{92.9}+\frac{53.0y}{57.9}=0.63$$

$$x+y=1$$

where x = weight of burnt clay, and y = weight of calcined limestone. On solving the equations it is found $x=0.3151$ and $y=0.6849$. On this basis the ratio between the clay and the limestone is 1 : 2.173, while for the raw, unburnt materials it is 100 pounds of clay to 348.7 pounds of stone; a ratio which differs considerably from the one obtained by means of the Le Chatelier formula.

Owing to the fact that a great amount of data is now available concerning the composition of Portland cements, this method of calculation is justifiable and practical; any changes involving a decrease or an increase in the amount of lime must be made empirically in any case. Once having established the best proportion of a mixture, the daily mixture can be calculated from the raw materials available by the following simple calculation:

Let x=weight of limestone in charge.
y=weight of clay in charge.
a=per cent of calcium oxide in the limestone.
b=per cent of calcium oxide in the clay.
c=per cent of calcium oxide in the mixture.

Then, $C=\frac{ax+by}{x+y}$ or $x(a-c)=y(c-b)$ or $\frac{x}{y}=\frac{a-b}{a-c}$

In order to obtain an estimate as to the average composition of Portland cement, the following analyses, A and B are given. A is the average analysis of 17 American brands; B the average composition of several hundred samples of German cements:

Analyses of Portland cement.

	A.	B.
Silica	21.81	20.56
Alumina	7.35	7.37
Ferric oxide	3.16	3.24
Lime	62.51	62.74
Magnesia	2.26	1.63
Sulphuric anhydride	1.33	1.82
Loss on ignition	Not det.	2.87
Insol. in H Cl	do	1.75

In an extensive series of tests the writer has found the formula $x(2.8\ CaO)+y(2.0\ CaO.\ Al_2\ O_3)$ to apply to a considerable number of clays, resulting in good clinker in practically every case.

Trial burns may be made in a Fletcher pot-furnace, a small shaft-furnace[1] or a rotary kiln of laboratory size according to the amount of material to be burnt.

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[1] Ohio Geol. Survey: Bull. No.3, (IV).

As to the correction of certain defects developed in the clinker and the ground cement the following tabulation may be of assistance. The principal faults are: Difficulty of vitrification requiring too high a burning temperature; too rapid or too slow setting; inconstancy in volume; tendency to dust, or to break down to a powder after burning, due to the formation of an unstable dicalcium silicate.

Correction for defects of clinker and cement.

Defect.	Correction.
Too difficult to vitrify; burning temperature too high.	Decrease lime content or grind finer or add ferric oxide in the shape of an ore, or add small amount of fluorspar to raw cement.
Too fusible and "sticky."	Increase silica content of clay base and total lime content.
Sets too rapidly.	Increase silica content in clay base, or add fluorspar to raw mixture, or add ferric oxide to raw mixture, or grind gypsum with clinker. Store longer.
Sets too slowly.	Reduce silica content or grind clinker finer.
Not constant in volume (does not stand boiling test).	Store longer. Decrease lime content or increase content of ferric oxide, or increase silica content in clay base; grind raw mixture finer; reduce sulphur content.
Tendency to dust.	Increase lime content; quench clinker in water or cool rapidly in air; add ferric oxide to raw mix.
Too low in initial tensile strength.	Increase lime content and grind raw mix finer, or increase alumina somewhat, or grind clinker finer.
Too low in final tensile strength or showing a deterioration in strength.	Increase silica in clay base.

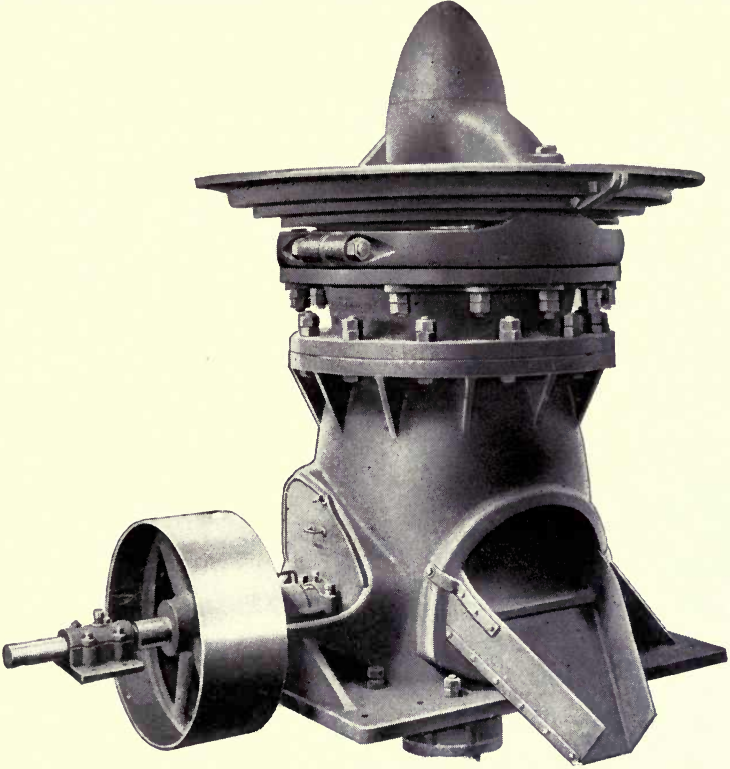
It is found in some districts, especially where loess clays are employed in cement making that the high silica-alumina ratio of these materials makes necessary the mixture of a silicious and more aluminous clay. This condition is likely to arise in southern Illinois. The calculation necessary for this purpose is simple, and is expressed by the equations:

$$\frac{a_1x+a_2y}{b_1x+b_2y}=r=3$$

$$x+y=100$$

in which a_1=per cent of silica in first clay.
a_2=per cent of silica in second clay.
b_1=per cent of alumina in first clay.
b_2=per cent of alumina in second clay.
x=parts of first clay.
y=parts of second clay.
r=desired silica-alumina ratio=3.

It is evident that the higher the one clay is in alumina, the less of it will be necessary to make up the desired mixture.



Gates rock crusher.

WINNING OF THE RAW MATERIALS.

In Illinois the principal materials available for cement making are the limestone and clays; and, hence, the dry process of working is the one generally to be employed.

The stone is either quarried or, in rarer cases, mined. The latter method would be necessary in some districts. Obviously quarrying is far cheaper than mining, involving not more than one-half the cost of the latter. In quarrying limestone, power-drills are now usually employed; and, in use of explosives, the stone is shattered as much as possible, consistent with economical working, so as to reduce sledging to a minimum. The cost of quarrying varies widely in different localities, but 20 cents per ton is probably not far from the average.

The shales and clays are worked either by means of the steam shovel, or they are quarried, or in the case of surface clays they may be gathered by plows and scrapers. The use of the steam shovel with a bucket capacity of about one cubic yard offers the cheapest means of winning clays or shales, and shows a capacity of from 400 to 800 cubic yards in ten hours. The cost of getting clays in this way varies from 5 to 12 cents per cubic yard. The quarrying of shales with judicious use of blasting powder and proper undercutting shows a cost of about 25 cents per cubic yard. The plow-and-scraper method is suitable for shorter distances, and in connection with the wheel scraper for distances as great as 500 feet. By the use of a dumping platform, which permits dumping of the scraper into cars or wagons, greater areas may be covered. The cost approximates 20 cents per cubic yard.

According to the distance of the quarry from the mill, and the topography of the country, tramways driven by cable, electric or steam locomotives, or aerial cableways are used for the transportation of the materials to the plant.

GRINDING THE RAW MATERIALS.

Introduction.

After arrival at the mill of the materials it is the task of the cement manufacturer to grind them together, to burn them to vitrification, and again to reduce the resulting clinker to the required fineness.

The mixing of the constituents in most dry-mills is done as follows: The rock is brought to the mill in cars and is dumped into large heaps. The clay material is likewise dumped and stored in piles. Samples for analysis are taken from the piles of stone and of clay. It is evident that under these conditions it is difficult to obtain average samples of either material, and hence it frequently happens that an analysis made from the sample collected comes far from representing the average composition. The only solution of this problem is to obtain very large samples and to reduce them by means of special sampling machinery.

After the analyses of the two materials are obtained, the rock and the clay are loaded on buggies and the proper calculated charge of each weighed out. The materials are then dumped into the crusher. Sometimes the samples for analysis are obtained at the quarry, and, in this case, the car-loads are weighed as they come from the quarry.

By far the most satisfactory method of mixing would be the following procedure: Both the rock and the clay should be passed separately through the coarse and intermediate grinding machines and reduced to a size smaller than that corresponding to the 10-mesh screen as delivered from the ball mill or similar machines. This size then should be stored in bins not larger than necessary to hold a half-day's run. By having a sufficient number of such bins it would be possible to sample these thoroughly and, hence, to control the composition of the mixture with accuracy and certainty. Since in dry mills there is usually no possibility of correcting any over-limed or over-clayed charge after it is on its way to the kilns, it is exceedingly important to secure the greatest possible accuracy in proportioning the mix.

The grinding of the raw materials may be considered to take place in three stages, coarse, intermediate, and fine. The machines commonly employed in the cement industry for these purposes may be described as follows:

COARSE-GRINDING MACHINES.

The machines which take the stone and the clay as they come from the quarry, and reduce the mixture to something less than inch-size are represented by two types:

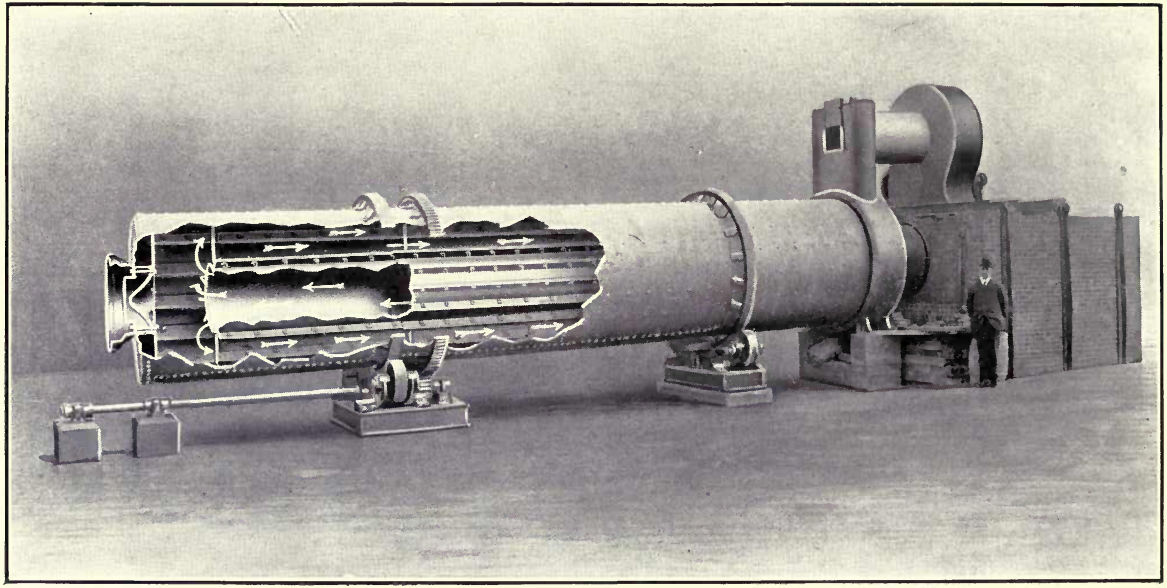
Gates crusher.
Blake crusher.

The first machine (Pl. VI) is the one most generally used, and its crushing action depends upon gyrating, vertical spindle, the upper part of which has the shape of a truncated cone. The latter rotates within a conical space representing an inverted cone. The crushing is continuous between the crushing surfaces, and the spindle follows an eccentric. This causes the head to approach and recede from the concave grinding surface of the shell surrounding the cone. The movement at the bottom of the truncated cone is greater than at the top. The fineness of the output can be regulated by adjusting the width of the throat. The cost of crushing is approximately 2½ cents per ton.

The Blake jaw crusher, is the well known type employed in crushing road metal, and its action is intermittent. Its capacity per horsepower per hour is less than that of the spindle crusher, and it has not found general application in the cement industry.

Roll crushers are used in at least one instance for rough grinding, but the principle does not seem to find favor in the industry.

For the purpose of facilitating grinding, especially of the clay, it is necessary in many cases to dry either the clay component or both the latter and the lime material. The rotary dryer seems to be the accepted form. The materials to be dried after preliminary crushing are introduced at the upper, cool end of the drying tubes, and discharged at the lower. One type of dryer consists of a plain, straight tube, through which the gases pass in the opposite direction to the material, and are drawn



Rotary dryer.

off while still at a fairly high temperature. In another type, a central flue is arranged through which the hot gases pass from the furnace and are returned through the space between the outside shell and the flue. In this case the material is fed through the front head into the space between the two shells, is picked up by lifting buckets, and dropped on the inner shell. By the revolution of the machine it is dropped again to the outer shell to repeat the operation until the inclination of the machine brings it to the rear end, where it is elevated and discharged through the center of the rear head. See Plate VII. According to the nature and moisture content of the material to be dried the capacity of a rotary dryer may vary from 10 to 35 tons per hour.

INTERMEDIATE-GRINDING MACHINES.

There is more diversity in machinery designed to reduce the material coming from the crusher, to a size passing the 16-mesh screen. There are also in this class some machines which combine both the intermediate and fine-grinding function. This feature is not to be recommended and does not represent American practice. The highest efficiency is obtained by employing one machine for one grade of work. The following types are used in American practice:

Ball mill,
Disintegrator,
Kent mill,
Rolls,
Dry-pan.

THE BALL MILL.

Probably the ball mill is most widely used for the intermediate grinding of the raw mixture. Plate VIII illustrates this type of machine. In its simplest form it consists of a cylinder revolving around its horizontal axis with grid plates around the circumference. The grinding is done by steel balls. The grinding surface is composed of perforated, chilled-iron plates arranged so that each laps the next. Steps are formed in this manner and the balls drop from one to the other. The grinding space is surrounded by two screens through which the finer material passes while the coarse particles are returned to the mill. The material to be ground is charged through openings in the hub. The power required is from 30 to 40 H. P., and the capacity varies according to the hardness of the materials from 4 to 6 tons per hour.

The kominuter has twice the length of a ball mill and about the same diameter, and its capacity is supposed to be twice as great.

The prominent advantage of the ball mill type of machine is the fact that it produces thorough mixing and blending as well as grinding.

DISINTEGRATOR.

The disintegrator is a true impact crusher, and its best developed type is probably the hinged-hammer disintegrator. The crushing is done by the blows imparted by a series of hammers revolving at a high speed around a horizontal axis. This is quite an efficient machine for raw-grinding; and when equipped with water-cooled journals it can work the hot material issuing from a rotary dryer. Eckel[1] reports that in one mill three Williams disintegrators handled sufficient raw mix for a capacity of 1,000 barrels per day—75 per cent of the ground limestone and shale passing the 20-mesh sieve. The power required was 18 H. P. for each mill. In another case this machine was known to grind 137 tons of hard stone and shale in 11 hours—84 per cent of the mixture passing the 20-mesh sieve. The machine required 75 H. P.

KENT MILL.

The Kent mill consists principally of a revolving ring and three rolls pressing against its inner face. The rolls are convex and the ring is concave, and tracks on the rolls. Springs support the rolls yieldingly and the rolls support the ring so that the four crushing parts are free to move. The material falls from the inlets to the inner face of the ring. Centrifugal force holds it there in a layer an inch deep. It revolves into the ring and passes under the rolls. The latter are pressed by the springs outward against the stone on the mill with a pressure adjustable to 20,000 pounds. As the rolls pass over the rock they crush it against the ring while the crushed material plows off each side of the ring into the casing and is discharged.

In late models of this machine considerable change has been made, which also results in a greater output (Pl. IX). The capacity of the Kent mill for the intermediate grinding of limestone is said to be close to 6 tons per hour with a consumption of about 25 H. P.

ROLLS.

The only American plant using roll crushers for intermediate grinding is that of the Edison Company, at New Village, N. J. The rolls used here are 36 inches in diameter with 30-inch face, and run 90 revolutions per minute. The material makes two passages through a set of three rolls. There is no doubt that rolls are the most efficient type of machine from the mechanical standpoint.

DRY-PAN.

The dry-pan or edge-runner consists of a revolving pan, usually 9 feet in diameter, upon which run two heavy mullers. A space about 12 inches wide around the circumference is filled with perforated plates. The grinding is done on the solid plate and the crushed material is scraped on to the perforated plates by fixed scrapers. The machine is well suited for grinding shales, but is less efficient with hard limestone or soft clays. A 9-foot pan may show a capacity as high as 10 tons per hour, and it consumes from 30 to 40 H. P.

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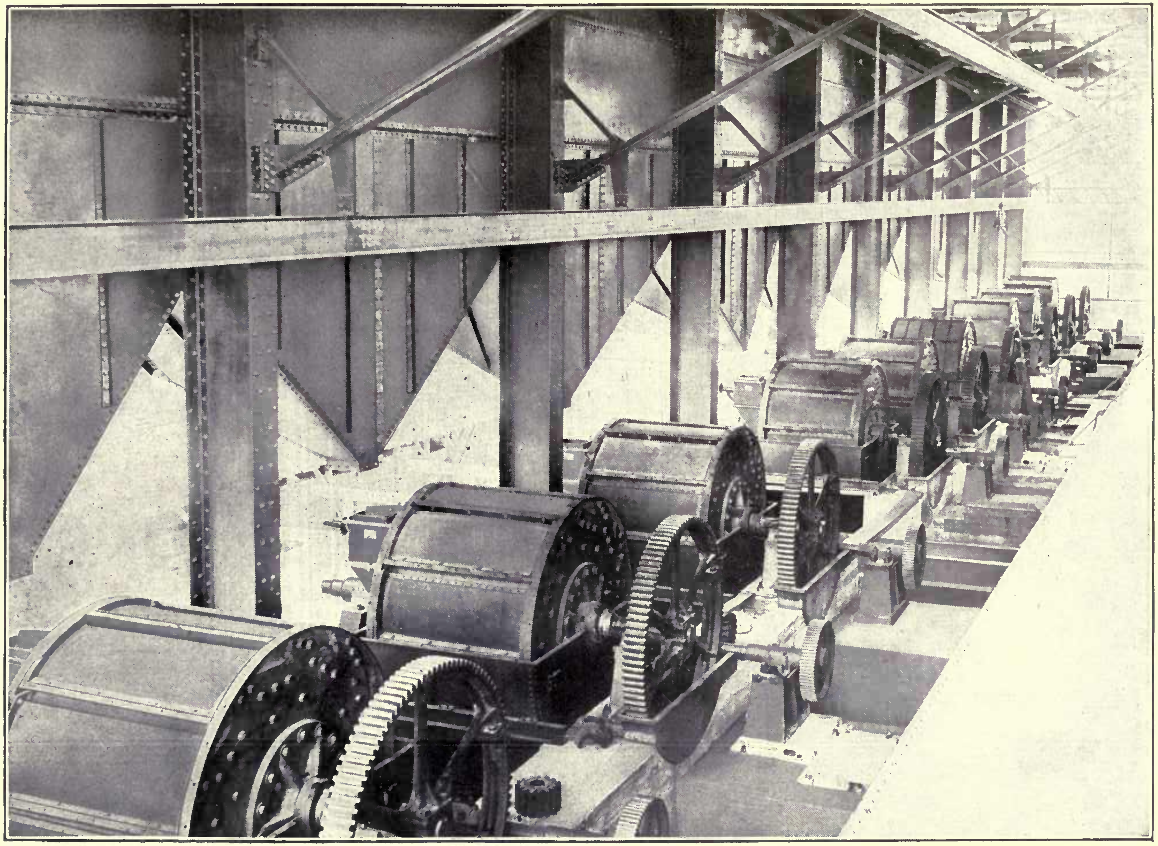
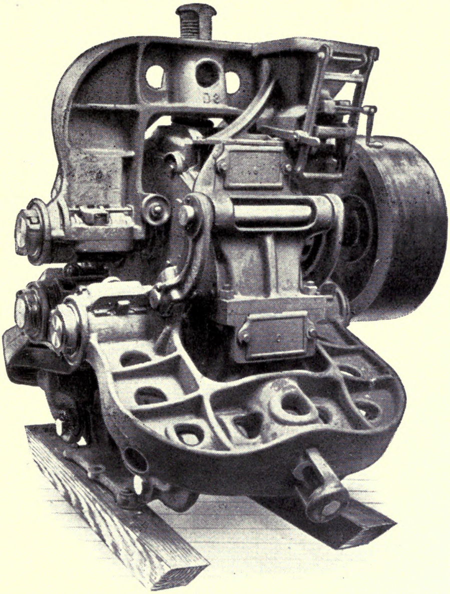
[1] Cements, limes, and plasters, p. 467.



Ball mill installation.



Kent mill, Maxecon type.

FINE-GRINDING MACHINES.

There are two principal types of fine-grinding machines:

The tube mill.
Centrifugal grinders.

TUBE MILL.

The tube mill (Pl. X) consists essentially of an iron shell from 16 to 22 feet long and from 4 to 5 feet in diameter. It is lined with some hard material like flint and is filled somewhat above the axis with flint pebbles which weigh about one to three pounds each. This tube is supported by two heavy hollow shafts, through which the material enters at one end and discharges at the other. A screw feeds the material into the hollow shaft. At the exit end a screen prevents any pebbles from being carried out. The pebbles are charged through a manhole. As the tube rotates the pebbles are carried up the sides to a certain height, whence they drop back to the bottom, describing a curvilinear path. The pulverization takes place principally by the impact of the falling mass of pebbles, the action being similar to that of a stamp-mill. The material to be ground assumes the same motion as the pebbles and distributes itself within the spaces. Owing to the fact that the mill is inclined slightly towards the discharge end, the mass constantly moves forward, though it has been stated that this inclination is not necessary.

The grinding effect depends on the vertical distance of the drop, the velocity of the drum, and the weight and number of the pebbles. Fischer[1] calculates the most favorable speed of the tube mill from the relation:

$$N = \frac{23 \text{ to } 28}{\sqrt{\text{Diameter}}}$$

where N=number of revolutions per minute and the diameter is expressed in meters.

Mellor[2] proposes the theoretical calculation:

$$N = 58.34 \sqrt{\frac{1}{d}} \text{ revolutions per minute,}$$

in which d= internal diameter, in feet, less the average diameter of the pebbles. The latter writer differentiates between dry and wet grinding, and suggests for dry operation:

$$N = 62.1 \sqrt{\frac{1}{d}} \text{ revolutions per minute.}$$

For wet grinding he proposes:

$$N = 43.3 \sqrt{\frac{1}{d}}$$

With reference to the work actually performed in grinding, Rittinger says that it is proportional to the product of the weight of material

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[1] Zeit. Ver. Deut. Ing., 48, 1905, p. 437.
[2] Trans. English Ceramic Soc., 1910, p. 50.

ground in unit time and the difference in the surface factors before and after grinding. The charge of pebbles according to James[1] should be for dry grinding:

$$W=44\ V.$$

where W=weight of pebbles and V=volume of tube mill, in cubic feet.

The capacity of this machine varies, according to the kind of material to be ground, and frequently a 22x5-foot tube mill shows a capacity of six tons of raw stock per hour. The power consumed is from 70 to 75 horsepower, though momentarily about 120 horsepower may be necessary to start the mill. The average power consumption of 5 tube mills, 22x5 feet, was found to be in one case 333 horsepower, or about 67 horsepower per mill.

The tube mill is probably the most generally used machine for the fine grinding of the raw stock. This is due to its simplicity of construction and to its thorough blending and mixing of the raw materials. The slower the feed the finer will be the grinding, though it is extremely important that the charging be done as uniformly as possible. As far as the quality of the work is concerned, it is doubtful whether any other machine can accomplish just the kind of task performed by the tube mill, although its power consumption for the same reduction is probably greater than that of some other types. The averaging, intimate mixing, and fine grinding make this mill the safest for this important part of the work.

The importance of fine grinding of raw materials can hardly be emphasized too strongly, and it is evident that the success of the entire process hinges upon it. From the factory standpoint it is, therefore, exceedingly important to determine whether the grinding has been done sufficiently fine so that no trouble may arise from "hot" cement, inconstancy in volume; and so that the burning temperature need not be too high. This may be done quite readily by obtaining a tube-mill sample, heating a weighed amount of it to white heat over a blast lamp, and treating the cooled material with strong boiling hydrochloric acid solution, after which the residue is filtered and washed. This is then treated repeatedly with hot sodium carbonate solution, followed by washing with dilute acid and finally with water.

If the grinding has been carried far enough there should be practically no residue left. The presence of insoluble material indicates the necessity of finer grinding. On the other hand, it is quite possible that in some cases the grinding is carried further than necessary, which is equivalent to a waste of power. In this case, of course, the rate of feeding may be increased.

CENTRIFUGAL GRINDING MACHINES.

The most prominent members of the centrifugal type, in which the grinding is done principally by impact and percussion, are the Griffin mill—both the one- and the three-roll type; the Huntington; the Fuller-Lehigh; and the Raymond mill.

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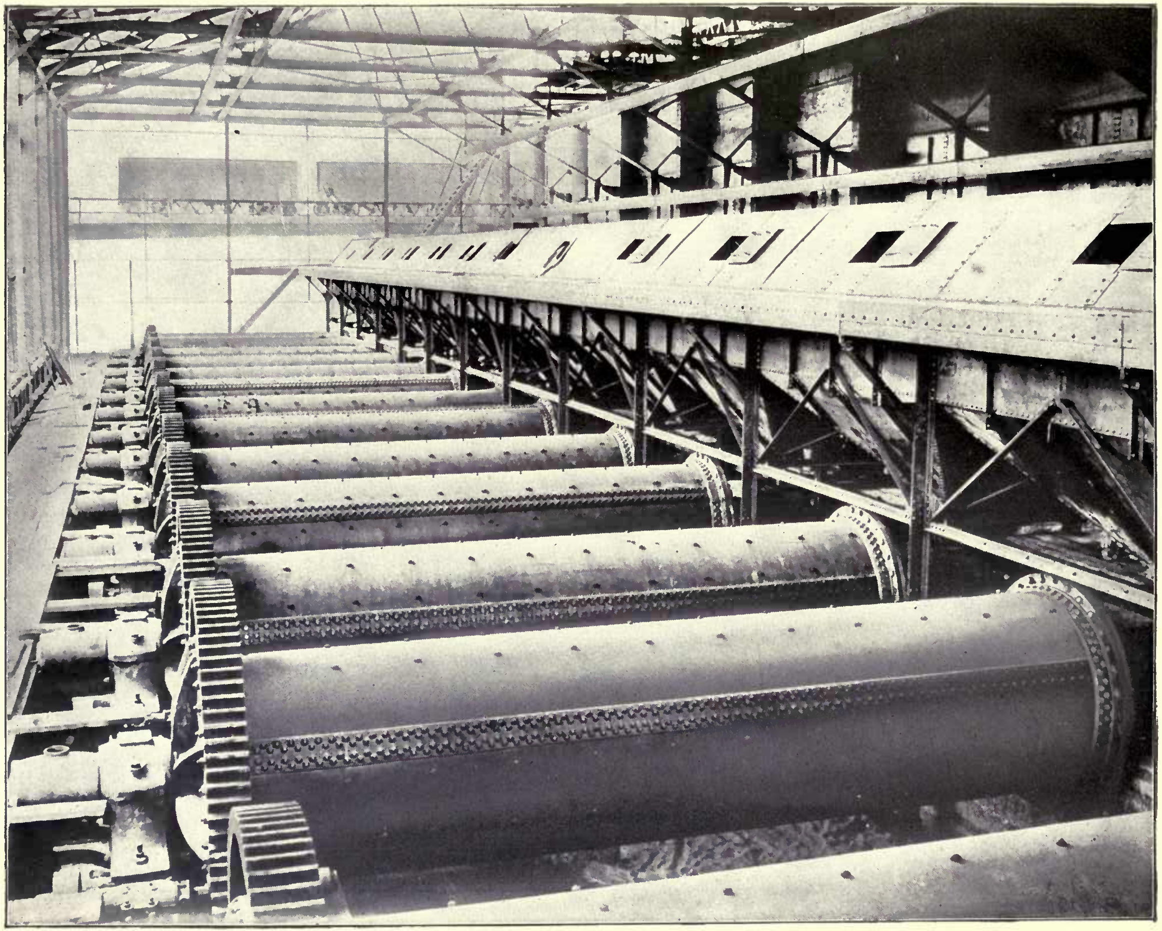
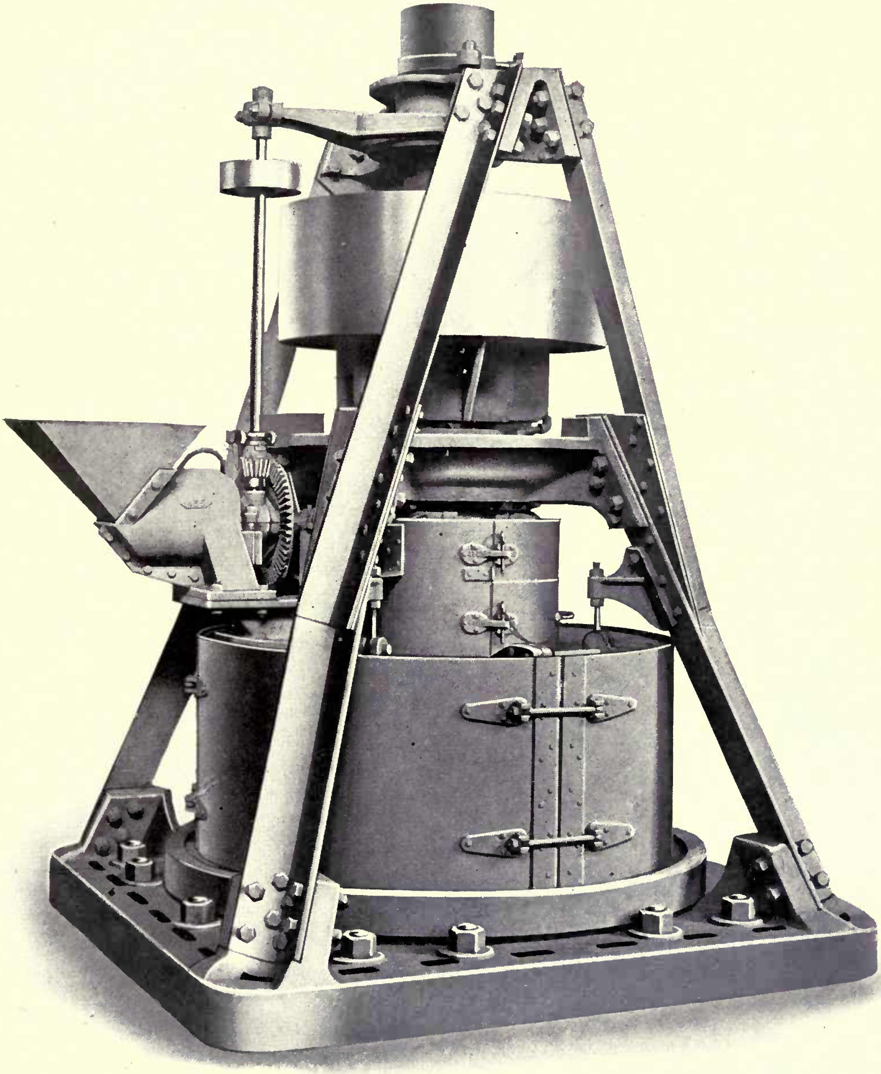
[1] Eng. Min. Jour., 79, p. 511.



Tube mill installation. (Allis-Chalmers Co.)



Griffin mill.

In the Griffin mill (Pl. XI), the grinding is accomplished by means of a roll secured to the lower extremity of a shaft which is free to swing in any direction within a casing. The latter consists of the base or pan containing the ring or die against which the roll works, and upon the inner surface of which the pulverizing is done. In dry pulverizing the pan has a number of downward openings outside of the ring, which lead into a receptacle from which the material is taken by a conveyor. Upon this base a screen is secured which is surrounded with a sheet-iron cover. To the top of this is fastened a conical shield with open apex through which the shaft works. A fan is located just above the roll, and shoes or plows just below it. In starting the mill, the roll assumes its vertical position and must be pushed out of center in order that centrifugal force may come into play. Thus, the roll is forced against the ring and is rotated within the die in the same direction that the shaft is driven, but in contact with the die it travels in the opposite direction from which the roll is revolving with the shaft, thus giving the mill two direct actions on the material to be ground.

The material to be ground when fed into the mill is stirred up by the shoes and thrown against the ring so that it is crushed by the roll. The fan attached to the shaft above the roll draws in air at the top of the cone, and forces it through the screens into the discharge. A 16-mesh screen delivers a product of which over 90 per cent will pass the 60-mesh screen.

The mill makes 200 revolutions per minute, and requires approximately 25 horsepower to produce 5,000 pounds of finely ground stock.

The Griffin mill differs from the tube mill in that it possesses a tendency to segregate constituents of different specific gravities or size of grain. Hence, it does not possess the blending effect of the ball-grinding machines, and for this reason does not seem to be so well suited for the best preparation of the raw mixture. While the mechanical efficiency of the machine is good its repair costs, calculated to a comparative basis, are said to be higher than those of the tube mill.

The three-roll Griffin mill with 40 horsepower is said to grind, per hour, about five tons of limestone mixture so fine that 96 per cent passes through a 100-mesh screen.[1] According to these figures the improved mill would have a decided advantage over the one-roll Griffin, especially as the repair costs are supposed to be lower.

The Huntington mill is similar in construction to the Griffin mill but it has not found any extensive use in the cement industry.

The Fuller-Lehigh mill (Pl. XII) depends for its grinding action upon four 12-inch steel balls following a circular groove in which the pulverization takes place. It is claimed for this machine that it produces a greater amount of impalpable powder than other apparatus. Its capacity per hour with a consumption of 35 horsepower is about five tons of raw mix, passing the 100-mesh sieve. The Fuller-Lehigh mill is finding extensive application in the cement industry at present, and two Illinois cement plants have these machines as part of the grinding equipment.

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[1] Meade, R. K., Portland Cement, p. 91

In the Raymond mill the grinding is accomplished by rollers thrown against a steel ring by centrifugal force, in a manner somewhat similar to that of the Griffin mill. A plow is located ahead of each roller and constantly throws a stream of material between the roller and the ring. This is especially adapted to work with air separation, in which case the air enters the mill through a series of tangential openings around the pulverizing chamber. That portion of the material which is reduced to the required fineness is carried up by the air current to the receiving receptacle. The material not ground sufficiently fine by the first roller is carried between the succeeding roller and the die to be ground again. The Raymond mill is illustrated in Plate XIII; its combination with the air separator, in Plate XIV.

The writer some years ago looked into the question of fine raw-grinding and made mechanical analyses of the product delivered by various mills. The results of this work[1] are compiled in the following table:

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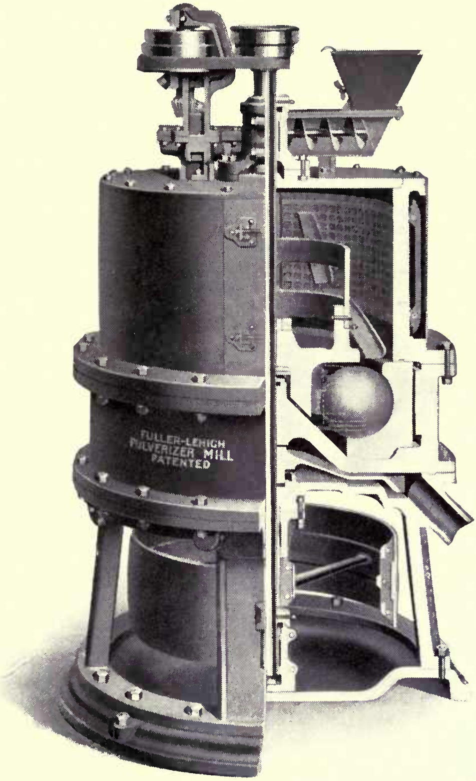
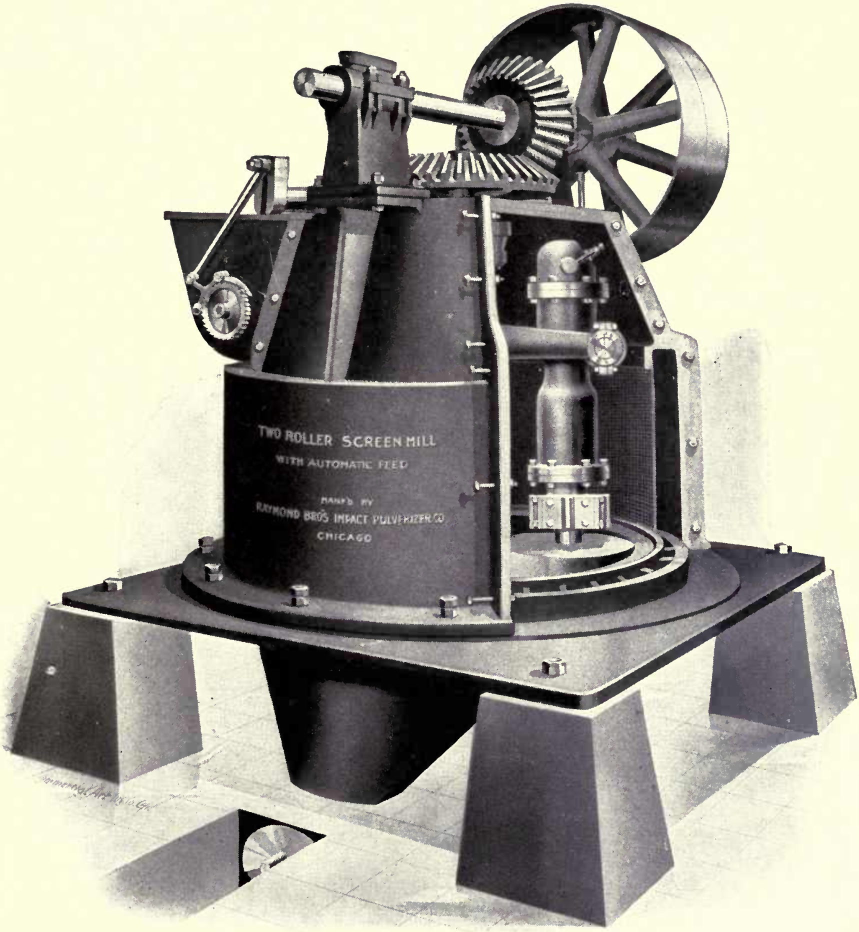
[1] Ohio Geological Survey, Bull. No.



Fuller-Lehigh mill.



Raymond mill.

Mechanical analyses of product of fine, raw-grinding machines.

Number.	Materials used.	Fine—grinding machine used.	Residue on 80-mesh sieve.	Residue on 120-mesh sieve.	Residue on 200-mesh sieve.	Grains average diameter 0.00210 inch.	Grains average diameter 0.00088 inch.	Grains average diameter 0.000435 inch.	Finer than last size.	Total amount finer than 200-mesh.	Remarks.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
1	Limestone and shale	Emery mills	2.00	8.89	4.85	16.93	8.96	8.70	48.68	83.27	Ground dry
2	Cement rock and limestone	Griffin mills	16.38	11.57	4.75	16.21	13.29	7.61	30.17	67.28	..do
3	Limestone and clay	Tube mill	3.03	7.42	3.68	23.77	17.52	10.26	34.33	85.88	..do
4	Limestone and clay	..do	7.40	9.56	2.48	17.72	8.96	8.83	45.05	80.56	Ground wet
5	Marl and clay	..do	3.04	5.50	5.21	21.31	12.63	9.61	44.72	87.27	..do
6	Marl and clay	..do	30.46	4.28	2.17	6.73	10.61	9.31	36.44	63.09	..do
7	Marl and clay	..do	2.48	5.23	2.47	16.14	14.22	12.01	47.46	89.83	..do
8	Marl and clay	..do	26.74	6.99	2.13	10.52	9.77	7.67	36.18	64.14	Shells in marl quite evident

From these results it is apparent that the larger part of the ground material passes the 200-mesh sieve, and under the best conditions almost 90 per cent corresponds to this fineness. There is reason to believe that the most important part of the mixture is that which is considerably finer than the size corresponding to the 200-mesh.

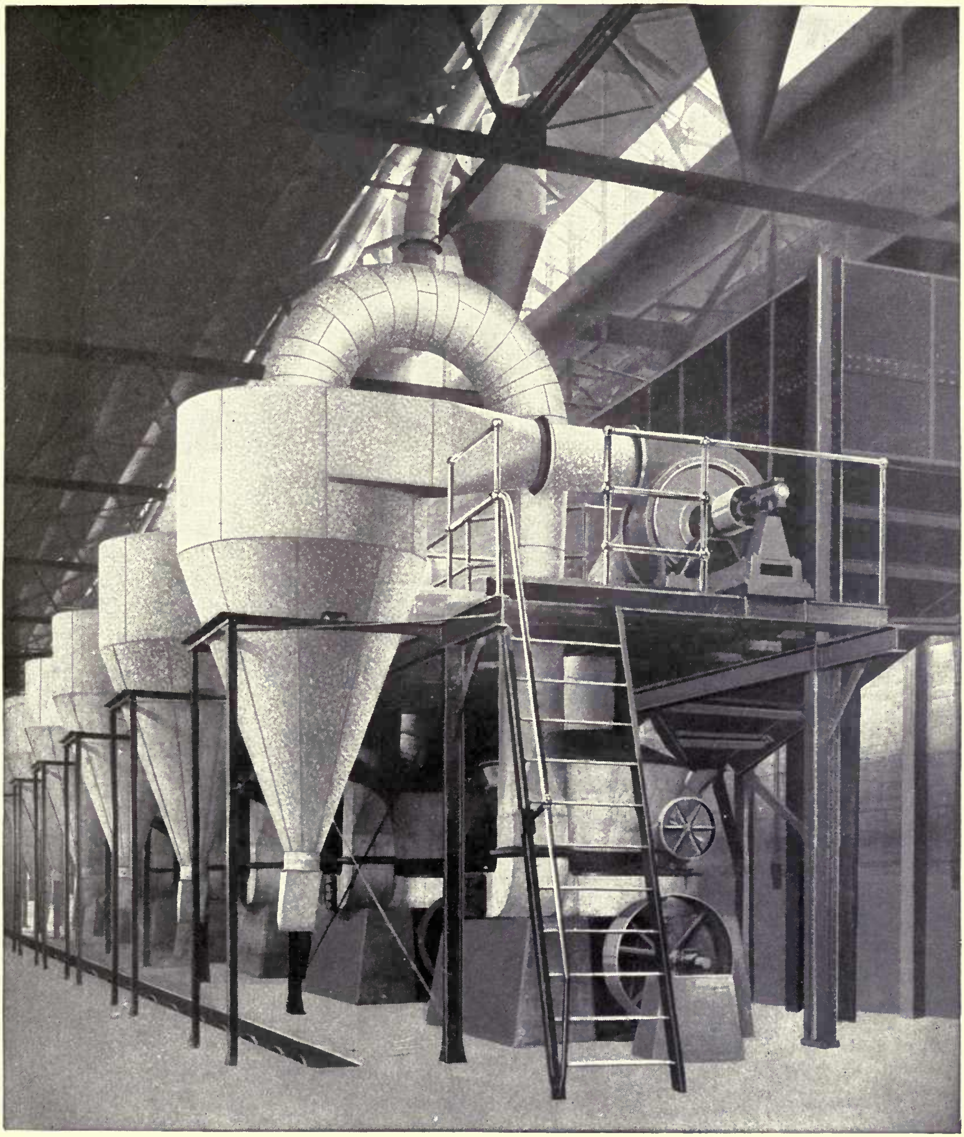
Owing to the fact that the reduction of the clay to a fineness which permits of complete reaction with the lime is frequently the greatest difficulty, it might be advisable with some clays to grind them to the desired fineness before blending them with the limestone. This applies especially where a plant is compelled to use a glacial or loess clay. The cost of the raw-grinding is thus necessarily increased, but it would not be as great as where both the stone and clay are to be ground until the latter has attained the requisite fineness. In such cases, which might easily arise in certain Illinois districts, the clay would be dried in a rotary dryer, put through a Williams mill or a dry-pan, according to whether gravel or coarse material is present, and finally through a Fuller mill. The finely ground clay could then be weighed out with the requisite amount of limestone which had passed through an intermediate grinding machine, after which the mixture should be reduced in a tube mill.

BURNING THE MIXTURE.

The ground material is stored in bins at every stage of the process so that the individual mills are to some extent independent of the preceding machine. Finally the mixture arrives at the storage bins ahead of the kilns and is fed to the latter in a steady flow by means of a screw conveyor.

The rotary kiln (Pl. XV) universally employed in the cement industry is a huge steel tube, lined on the inside with fire brick, usually from 90 to 125 feet in length, and from 7 to 9 feet in diameter.

The rotary kiln cylinder is provided with two flanges about 5 inches wide which are supported upon two pairs of heavy cast-steel rollers. The kiln is rotated by means of a girth gear of cast iron or steel, provided with expansion leaves. At the lower end a heavily bricked head is supported by four cast-iron wheels which permit it to be moved away from the kiln. The upper end of the kiln connects with a short, brick stack which is surmounted by a steel stack about 60 feet high. The feeding device consists of a water-jacketed, screw conveyor through the stack. The kiln usually is given an inclination of 3 in 60 feet, and is rotated at the rate of one revolution per minute. At the lower end of the kiln, powdered coal is blown through a single blast pipe. The coal dust is usually located in a large bin in front of the kiln, and is carried to the blast pipe by a screw conveyor. The air pressure is produced by a fan, though the air supplied from this source represents but part of the volume necessary for combustion, and a large part is admitted through the openings in the head and at the clinker discharge. There is a tendency with the long kilns now in use to employ a higher



Raymond mill with air separators.

pressure for the injection of the coal so as to extend the high temperature zone of the kiln, and hence to increase the capacity. In this case, of course, the volume of air introduced with the powdered coal becomes still smaller, and combustion must depend principally upon air drawn in through the head. However, pressure draft is bv no means necessary for the burning of the cement. Provided a sufficiently high stack is used, the natural draft produced by the elevated temperature of the exit gases is sufficient to carry on the combustion of the fuel. While usually the rotary kiln is of uniform diameter throughout, some have proposed to reduce the diameter at the cool end, so as to increase the velocity of the charge, and at the same time to widen the kiln at the lower end in order to retard the flow of the hot gases in the vitrification zone. This idea seems to have found favor in a number of European cement mills, and it is claimed that in this way the fire-brick lining is subjected to less severe treatment and shows much greater durability.

The fuel feed may be regulated by means of a speed controller or by ordinary stepped pulleys. It is evident that most of the coal ash remains in the kiln and adheres to the clinker, though part of it is carried out through the stack. It is hence desirable that the content of ash in the coal be as low as possible, although its deleterious effects have been greatly exaggerated. Likewise the composition of the coal with regard to the content of volatile combustible matter and fixed carbon need not be confined to such narrow limits as was formerly supposed. If the coal is ground fine, such grades of Illinois coal as Springfield screenings and similar fuels, averaging about 15 per cent of ash, may be used without difficulty.

The best preparation of the coal includes first putting it through an intermediate grinder like the Williams mill or ball mill, and then conveying it to a rotary dryer, so adapted to this purpose that the hot combustion gases do not pass through the space filled with the coal. Such a dryer may consist of two concentric cylinders, so arranged that the hot gases pass through the inner cylinder and return through the space between the two shells. The coal is fed between the shells, thus being heated by the hot inner flue and by the products of combustion on their return. In another type, the coal passes through a rotating cylinder encased in brick work, and the heat is applied to the outside of the shell.

From the dryer the coal goes to a fine grinder which is either a machine of the centrifugal type or a tube mill. The former kind is to be preferred for this work.

In some cases the coal, nut size, goes direct from the car to the dryer and thence to a bin which feeds to a so-called aeropulverizer. This consists of a three-stage disintegrator which creates enough air current to carry the finer coal particles to the kiln. By means of a settling chamber the coarser particles are returned to the mill for regrinding. It is somewhat doubtful whether this preparation is sufficient for low grade coals, although it has certainly the merit of simplicity and cheapness of operation.

The theoretical fuel consumption in the burning of Portland cement has been estimated by Meade to be about 30 pounds of good coal per barrel, but this figure is greatly exceeded in practice, even in the modern long kilns. Thus, a coal consumption of about 90 to 100 pounds per barrel is common. According to the clinkering temperature, the fineness of grinding, etc., the average capacity of a 100- to 120-foot kiln may vary from 450 to 600 barrels per day of twenty-four hours. The writer has known this capacity to be greatly exceeded under favorable conditions.

P. C. Van Zandt[1] estimates the heat distribution of a long kiln to be as follows:

Heat analysis of coal used in burning one barrel of Portland cement. Total heat.

100 lbs. coal used to burn one barrel (at 13,400 B.T.U. per lb.) 1,340,000 B.T.U.

Heat used in combustion.

	Per cent of total.
Heat consumed by products of combustion, 398,600 B.T.U.	29.70
Heat consumed by 50% excess air in kiln, 201,400 B.T.U.	15.30
Total	45.00

Heat used in burning cement.

12 lbs. water evaporated and heated to 1,500° F., 20,832 B.T.U.	1.56
600 lbs. mix heated to approximately 1,000° F., 112,800 B.T.U.	8.40
450 lbs. limestone decomposed and CO_2 driven off, 344,250 B.T.U.	25.60
204 lbs. gases (liberated from mix) heated to 1,500° F., 24,480 B.T.U.	1.83
384 lbs. mix heated to approximately 2,500° F., 115,200 B.T.U.	8.60
6 lbs. sulphur anhydride liberated at 1,900° F., 11,340 B.T.U.	.85
Unaccounted for (assumed lost in radiation) 111,098 B.T.U.	8.16
Total	55.00

Heat lost (Available for recovery).

	Per cent.
Going up stack (figuring gases at 1,500° F.)	49.90
Going out with clinker (2,500° F. down to 60° F.)	14.19
Radiation from shell (by subtraction)	8.16
Total	72.25
This gives an approximate total thermal efficiency of	27.75

The 55 per cent of the total heat in one hundred pounds of coal used in burning a barrel of cement may be analyzed as follows, showing where the heat goes that is actually used in burning the cement and not used in heating the products of combustion themselves:

	Per cent (Approx.)
Driving off moisture	2.35
Driving off CO_2 (and SO_3)	46.58
Heating gases driven off	8.92
Heating mix	27.35
Radiation of heat	14.80
Total	100.00

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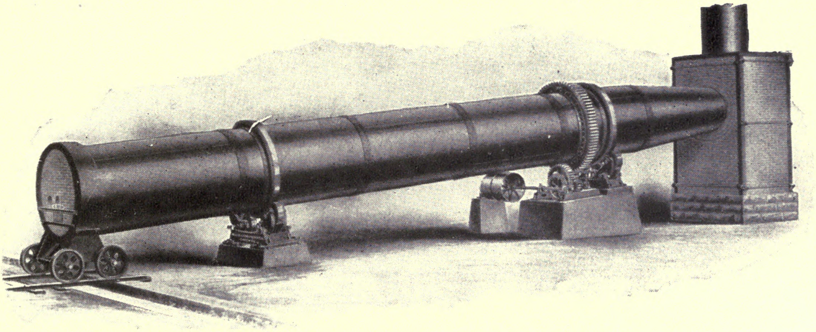
[1] Eng. News, 66, p. 702.



Rotary kiln installation.

In this approximation the heat lost by radiation seems to have been under-estimated.

There is no reason why it should not be possible to employ mechanical stokers for the burning of cement in rotary kilns, and the necessity of using low-grade fuel will undoubtedly bring about developments along this line. At the Pittsburgh plant of the Technologic Branch, U. S. Geological Survey, tests were conducted with a mechanical stoker using low-grade slack and passing the gases through a long combustion chamber, which clearly showed the possibility of maintaining high temperature for long periods without harmful fluctuations in temperature. It is evident that such installations would not only do away with the cost of coal grinding but would make possible the use of coals so high in ash that they could not be considered at all for cement burning under the present process.

CLINKER GRINDING.

The red-hot clinker as it is discharged from the kiln usually drops into a link-chain pan-conveyor by which it is elevated and carried to a cooler or to a clinker pile. In most cases, however, no attempt is made to use the heat of the cooling clinker, which retains about 15 per cent of the heat consumed in burning. This is especially true where coal is cheap, since considerable additional capital is involved in the construction and operation of the coolers.

However, there are several systems of recuperators. One consists of revolving cylinders arranged beneath the kilns to receive the clinker as it leaves the kiln—the connection between the kiln and the cooler being as air-tight as possible. The air passes over the hot clinker into the kiln, thus being pre-heated. One cooler may serve two kilns. Another system includes vertical cylinders, containing iron, baffle plates and an annular space which collects the pre-heated air. From either type of cooler the clinker is conveyed to storage bins over the grinding machines.

The storage of clinker in the open air or in open sheds is desirable from the standpoint of power consumption since it is found that such clinker is ground more easily, and also requires a shorter time of storage in the cement bins. By having a sufficiently large area for the accumulation of clinker it might thus be possible to produce cement which could be shipped a short time after the finishing grinding or immediately from the conveyor belt.

For clinker grinding two classes of machines must be distinguished:

1. Intermediate grinders.
2. Fine grinders.

The first type includes the ball mill and the Kent mill; the second, the tube mill, the Griffin, and the Fuller-Lehigh mill. The latter machine may often be used as a preliminary grinder by operating it without screens or fan. The ball mill is being replaced by machines with greater power efficiency. There is no reason why machines of simple construction, such as the roll crusher, should not be used for this kind of work.

The capacity of the ball mill of the size requiring from 40 to 50 horsepower, may be said to vary between 20 and 25 barrels per hour. For the Kent mill, Maxecon type, it is claimed that 40 barrels of material passing through the 20-mesh sieve can be ground per hour with an average consumption of 25 horsepower.

Before charging the clinker to the grinding machine a certain amount of gypsum rock is added; usually not more than 2 per cent.

For fine grinding four machines are available, the tube mill, the Griffin, the Fuller-Lehigh, and the Raymond mill. A 22-foot tube mill, requiring from 80 to 90 horsepower, is said to yield 16 to 20 barrels of cement per hour; the Griffin, with 25 horsepower, 5 to 8 barrels per hour; and for a set of 11 finishing Fuller-Lehigh mills a clinker grinding capacity of 3,000 barrels per day is claimed.

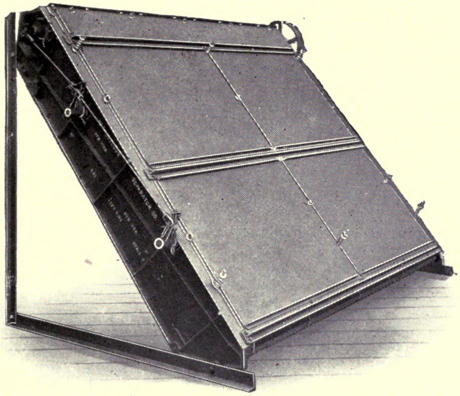
In this connection it may be stated that machines of the Kent-mill type can be used for fine grinding in connection with a system of vibrating or other screens. The Newaygo screen (Pl. XVI) is used for this purpose in a number of plants. The claim is made that the Kent mill grinds 10 to 12 barrels of cement per hour, with a fineness such that 98 per cent passes the 100-mesh sieve and 83 per cent the 200-mesh sieve.

In the mill of the Edison Portland Cement Co., both the intermediate and fine grinding is accomplished by means of roll crushers; the separation of the fines being effected by air separators.

Since in the intermediate grinding, irrespective of the machine, a portion of the clinker is reduced to the desired ultimate fineness, the use of a separator seems advisable to avoid bringing this finished part of the clinker to the fine grinder. This elimination may be effected by means of screens or air separators. The use of the latter has already been indicated under the topic of raw grinding in connection with the Raymond mill. The Raymond separator may be used in connection with any grinding machine and is thoroughly efficient and dust proof. The use of a similar system for the removal of the dust from the air is greatly to be desired from the humanitarian as well as from the economic standpoint.

From the fine-grinding machine the finished cement is carried by belts to the bins, where it remains until "cured" and ready for the market. If the clinker has been exposed to the air for a sufficiently long time, and if the composition is such that but little free lime is present, shipment may be made immediately.

In the consideration of fine grinding it is important to realize that the real cementing quality is inherent only in the fine cement flour; i. e., in that portion which passes at least the 200-mesh sieve. Thus a cement may pass the 100-mesh sieve commonly adopted as the standard, and yet be inferior to another material of which a larger part is in the form of dust. The measurement of the fineness of cement should really be carried farther than is possible either by means of an air separator,



Newaygo screen.

as suggested by Gary, or by beaker sedimentation in petroleum or alcohol. Eleven Portland cements examined by the writer showed an average content of fine material passing the 200-mesh sieve of 71.4 per cent; the samples having been washed through this sieve with alcohol.

In regard to the capacity of the different machines, Professor Carpenter gives the following summary:

Capacities of crushing and grinding machines.

Machine.	Capacity in tons per hour.	Horsepower used.
Rock crushers		1.1 per ton
Rolls		1.5 per ton
Griffin mill, rock	1.5 to 3.0	27 to 33
Griffin mill, clinker	0.8 to 1.5	27 to 35
Griffin mill, coal	1.5 to 2.0	16 to 24
Ball mills on rock, to 20 mesh	2 0 to 4.0	20 to 30
Tube mill, producing fine powder	2.0 to 4.0	70 to 80

Plate XVII indicates the sequence of the machines used in the several stages of the process. This arrangement is merely suggestive, and does not represent any actual plant.

TESTING CEMENT.

In commercial practice certain requirements are made as to the quality of Portland cement, which refer to:

Specific gravity.
Constancy in volume.
Fineness.
Time of setting.
Tensile strength.
Chemical composition.

SPECIFIC GRAVITY.

The specific gravity, in itself, is of but secondary significance. It was formerly supposed that by means of this determination underburnt clinker could be detected—it having been assumed that the density of well vitrified cement is lower than that of the underburnt material. This is in error, since the contrary is the case, owing to the fact that on progressing towards fusion nearly all silicates increase in specific volume, i. e., decrease in density. However, if the average specific gravity of the fresh clinker is known, the effect of storing may be detected by means of the decrease in specific gravity due to the absorption of water and carbon dioxide. The specific gravity of freshly calcined cement averages 3.1 to 3.2.

CONSTANCY IN VOLUME.

It is a necessary qualification in all cements that the volume shall be constant. A cement may, however, show the highly objectionable property of expanding, due either to an excessive amount of free lime, or to an excess of alumina, sulphuric anhydride, or magnesia. This evidently renders it unfit for most uses. Such cement may be detected as follows: Make up on clean glass a pat of the neat mortar, about 3 inches in diameter, one-half inch thick in the center, and tapering to a feather edge. This pat after storing 24 hours in a moist closet and boiling for three hours in water should not come off the glass nor show signs of cracking or disintegrating. If it should come off the glass, close inspection of the flat surface should show no warping. Fresh cement usually fails to pass this test, though it will do so after sufficiently long storage. Other proposed tests include: the direct measurement of the abnormal expansion of cement bars by means of micrometer gauges; immersion in a calcium chloride solution; the determination of the rise in temperature on setting; exposure to moist heat at about 100° F., etc. The boiling test is the one commonly employed, however, in cement-testing laboratories.

FINENESS.

As has been previously pointed out the real cementing substance is so fine grained that it cannot be differentiated by means of sieves but requires more refined methods of separation. This fact, however, is not yet recognized in the cement specifications proposed by different organizations, which ask simply that 95 per cent of the cement pass the 100-mesh sieve. This test can be no true indication of the real fineness.

TIME OF SETTING.

The time elapsing between the making up of the mortar and the beginning of the hardening is of evident importance. The point at which the cement has set is fixed arbitrarily by means of the so-called Gilmore or the Vicat needle. The former is simply a weighted, blunt point; the latter, a rod carrying a loaded plate on top, which runs in a guide and is provided with a pointer and scale. In each case the depth of penetration, or the failure to penetrate, is the indication of the stage of setting.

TENSILE STRENGTH.

The tensile strength of cement is judged from the behavior of cement or sand-mortar brickettes having the shape of a figure 8 and a cross section of 1 square inch at the middle. For this test the cement, either neat or mixed with three parts by weight of standard (Ottawa, Ill.) sand, is made up into a stiff mortar and molded in brass molds by hand. After remaining for 24 hours in a moist closet the specimens are immersed in water, where they are kept for 6. 13, or 27 days, according

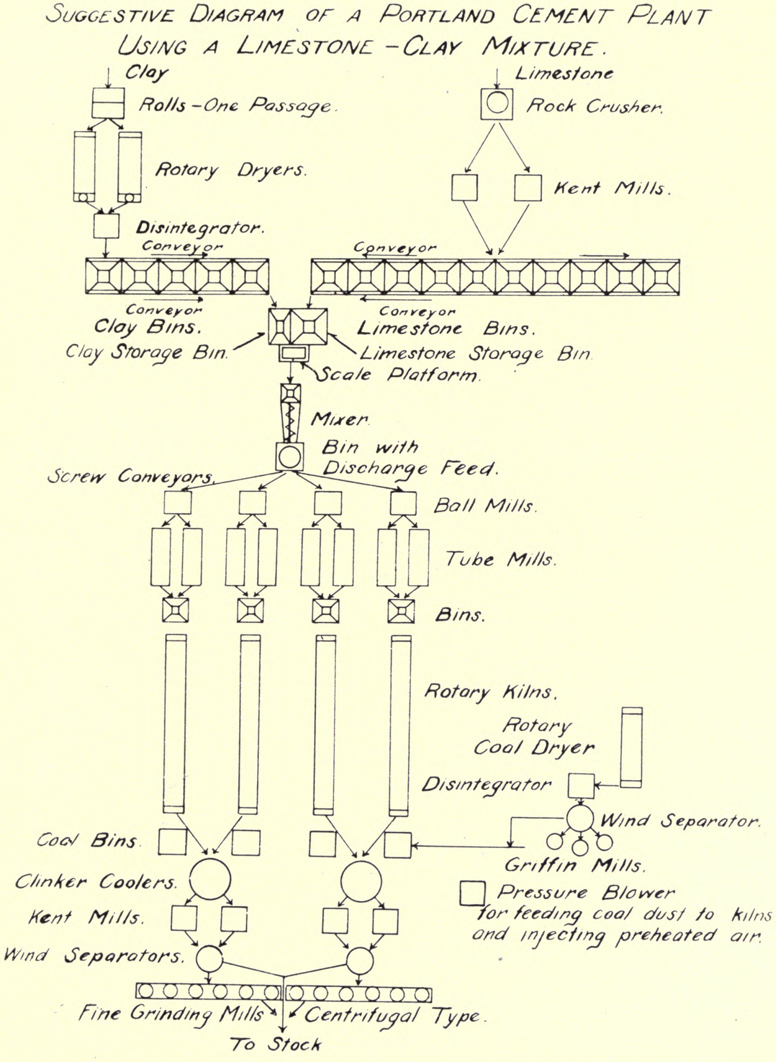


Diagram showing sequence of operations in Portland-cement manufacture.

to the time at which the strength is to be determined. The brickettes are broken in specially-designed, testing machines such as the Fairbanks, Olsen, Riehle, and others.

The requirements, according to the specifications of the American Society for Testing Materials, are the following minimum tensile strengths:

Neat clement:
24 hours in moist air..................175 lbs. per sq. inch
7 days (1 day in moist air, 6 days in water)............................500 lbs. per sq. inch
28 days (1 day in moist air, 27 days in water)............................600 lbs. per sq. inch

For a mortar consisting of one part by weight of cement and three parts of Ottawa sand, they are:
7 days (1 day in moist air, 6 days in water)............................200 lbs. per sq. inch
28 days (1 day in moist air, 27 days in water)............................275 lbs. per sq. inch

For details in regard to cement testing the transactions of the American Society for Testing Materials, and of the American Society of Civil Engineers should be consulted.

CHEMICAL COMPOSITION.

The only requirements usually made as to the chemical composition of cements are that the content of magnesia shall not exceed 4 per cent, and that of anhydrous sulphuric acid 1.75 per cent.

It is interesting in this connection to quote a resumé of the physical tests made upon 100 German Portland cements. The specific gravity of 67 samples was found to be between 3.05 and 3.15; and 61 in the calcined condition possessed a specific gravity between 3.20 and 3.25. The loss on ignition for 95 samples was as follows:

Loss on ignition.

Number of cements.	Per cent loss.
27	1 to 2
30	2 to 3
17	3 to 4
21	4+

The tensile strength of 53 samples made up into standard 1:3 mortar, after 28 days, varied from 284 to 355 pounds per square inch.

POWER REQUIREMENTS AND MANUFACTURING COSTS.

For the dry process of manufacturing cement it is a common rule to allow 1.5 horsepower for every barrel of cement manufactured. This would mean for a 1,000-barrel mill a power plant of 1,500 horsepower. Such an allowance is somewhat liberal but not excessive. From this it follows that power-plant economy requires the use of the best prime movers—either compound, condensing, steam-engines, or producer-gas engines. In many mills the power is applied by individual electric motors for each machine.

Meade[1] estimates the cost of a 2,000-barrel mill to be from $600,000 to $750,000, exclusive of the cost of the property.

The cost of manufacture, including depreciation, selling expense, etc., varies widely for different localities and different equipment, and probably is rarely less than 70 cents per barrel. Some of the optimistic estimates published clearly fail to include important cost factors.

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[1] Meade, R. K., Portland Cement, p. 161.

CHAPTER IV—THE STRATIGRAPHY OF ILLINOIS WITH REFERENCE TO PORTLAND-CEMENT MATERIALS.

(By Edwin F. Lines.)

INTRODUCTION.

In the present chapter a brief review of the geological formations in Illinois is given for the purpose of showing their relationship to the distribution of the materials used in the manufacture of cement. Since the calcareous element represents the greater portion of cement mixtures the limestones are described in more detail than the other rocks. Previous publications of the Survey and notes by members of its staff have been freely drawn upon for the material presented.

THE GEOLOGICAL COLUMN.

The grouping shown by the accompanying table is in accordance with the most recent interpretations:

Table of Illinois geological formations.

Quaternary.	Glacial till, sand, and gravel; loess and aluvium. Present as surface rocks everywhere except in northwest and extreme south. Thickness 30 to 225 feet.
Tertiary.	Lafayette, Lagrange, and Porters Creek. Clay, sand, gravel, and lignitic material. Occurs only in extreme south. Thickness 150 feet.
Cretaceous.	Ripley. Clay and sand. Occurs only in extreme south. Thickness 20 to 40 feet.
Pennsylvanian	McLeansboro formation. Shale, sandstone, *limestone*, fire clay, thin coal. Rocks lying above Coal No. 6. *Limestone usually thin and impure.* Occurs everywhere except in north and extreme west and south. Thickness 1000 feet. *"LaSalle" limestone and "Fairmount" limestone furnish material for Portland cement.* Carbondale formation. Rocks between base of Coal No. 2 and top of Coal No. 6. Shale, sandstone, *limestone*, coal. Thickness 150 to 320 feet. Pottsville formation. Sandstone, shale, fire clay, and thin coals. Thickness 50 to 750 feet.

Table of Illinois geological formations—Concluded.

Mississippian	Birdsville and Tribune.[1] Sandstone, shale and *limestone.* Thickness 500 feet. *Limestones form from one-fifth to one-third total thickness, and many of them afford good Portland cement material.*
	Cypress. Sandstone. Thickness 75 to 150 feet.
	Unconformity.
	Ste. Genevieve. *Limestone.* Thickness up to 250 feet. Frequently oolitic.
	St. Louis. *Limestone, brecciated or dense, shaly or dolomitic to comparatively pure.* Thickness 10 to 250 feet.
	Salem. *Limestone, oolitic in places, comparatively free from chert, light colored. Some portions suitable for Portland and others for natural-cement material* Thickness 10 to 125 feet.
	Warsaw. Shale and *limestone.* Formation is prevailingly shaly. Thickness 40 feet
	Keokuk. *Limestone* and shale. *Cherty limestones and interbedded shales. Certain beds are suitable for Portland-cement material.* Thickness 125 feet.
	Burlington. *Limestone, usually crystalline and nearly white, and locally nearly pure, but often very cherty.* Thickness 200 feet.
	Kinderhook. Sandstone, shale, and *limestone.* Sandstone and shale predominate. *Limestone is usually impure.* Thickness 25 to 200 feet.
	The Mississippian formations occur in the west and south.
Devonian.	Ohio shale. Brown to black or greenish shale. Thickness 90 feet.
	Hamilton. *Limestone, gray to brown and somewhat shaly or siliceous.* Thickness 50 to 70 feet.
	Onondaga. *Limestone* and sandstone. *Limestone light gray and tending to be crystalline.* Thickness 160 feet.
	Oriskany (Clear Creek chert). Gray to yellowish chert; in places decomposed into fine-grained unconsolidated masses. Thickness 240 feet.
	Helderberg (New Scotland). *Limestone, shaly and cherty to heavy bedded and crystalline.* Thickness 160 feet.
	The Devonian formations occur locally in the north, west, and south portions of the State
Silurian.	Niagaran. Dolomite, bluish or buff and massive. *Limestones* and shales near base of formation. Occurs in northeastern and locally in western Illinois. Thickness 50 to 150 feet.
	Clinton. *Limestone, containing chert in bands.* Occurs in Alexander county. Thickness 30 to 75 feet.
	Edgewood formation. *Limestone* and calcareous shale. Alexander county. Thickness up to 12 feet.
	Girardeau. *Limestone,* dark, fine grained, Alexander county. Thickness 33 feet.
Ordovician.	Richmond-Maquoketa. Shale and *impure limestone.* Occurs in northeastern, northwestern, and locally in southwestern Illinois. Thickness 75 to 175 feet.
	"Trenton-Galena." Includes Platteville and Galena of northwestern Illinois and the Joachim, Plattin, and Kimmswick of southwestern. *Limestones, tending to be shaly or dolomitic except Kimmswick which is coarsely crystalline and nearly white.* Thickness 80 to 440 feet.
	St. Peter. Sandstone, porous, friable, and pure. Occurs locally in northern part of State. Thickness 275 feet.
	Lower Magnesian. *Dolomitic limestone. Contains beds of natural-cement rock.* Occurs locally in western Illinois. Thickness 450 to 800 feet.

ORDOVICIAN SYSTEM.

LOWER MAGNESIAN LIMESTONE.

The Lower Magnesian dolomitic limestones are the oldest outcropping rocks in the State. The exposures are limited to LaSalle, Ogle, and Calhoun counties. In LaSalle county one outcrop extends about two miles along the Illinois river and one mile up Pecumsangum creek, just west of Utica; another extends about one mile up Tomahawk creek from its junction with Little Vermilion river; and a third extends a shorter distance along the Little Vermilion. In Ogle county an outcrop several hundred yards in length has been reported along Elkhorn creek; and in Calhoun county an outcrop a few rods in extent occurs at the base of Cap au Grés bluff.

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[1] Birdsville, Tribune, and Cypress comprise a unit which has been called "Chester" in Illinois reports.

The best section in the first-named district is exposed in the bluff on the north side of the Illinois river near Utica. A portion of the rock at this place is adapted to the manufacture of natural cement. A carefully measured section in this bluff in section 22 is given by H. C. Freeman[1] as follows:

Section in north bluff of Illinois river near LaSalle.

		Ft.	In.
31.	Sandstone, St. Peter; bottom 2 to 3 feet.....		
30.	Limestone, silicious and cherty beds	12	
29.	Limestone, silicious, oolitic	0	9
28.	Limestone	1	3
27.	Sandstone, calciferous	0	9
26.	Limestone	2	6
25.	Limestone, with some flints	4	6
24.	Sandstone, calciferous	1	
23.	Cement-rock, good	1	3
22.	Sandstone	1	
21.	Limestone, shaly, and clay	0	3
20.	Cement-rock, impure	1	10
19.	Sandstone, calciferous, good fire-stone, used for lining the kilns	3	
18.	Cement-rock, impure, breaks into small, irregular fragments, worthless	2	
17.	Flint	0	4
16.	Cement-rock, impure	0	2
15.	Limestone, arenaceous	0	10
14.	Cement-rock, impure	2	10
	Cement-rock, good	0	6
13.	Limestone, good quarry-rock	4	8
12.	Sandstone, calciferous	1	
11.	Limestone, irregular masses and broken fragments	3	
10.	Cement-rock, upper two feet not first quality	6	9
9.	Limestone, in beds of good quarry-rock; somewhat arenaceous, and irregular quality	4	6
8.	Cement-rock, impure	2	
7.	Limestone	1	6
6.	Cement-rock, good	0	10
5.	Sandstone, calciferous	1	
4.	Limestone	1	2
3.	Cement-rock, fair quality	1	6
2.	Limestone, upper silicious	6	
1.	Cement-rock, good, full thickness not ascertained as it extends below the bed of the railroad. It contains two bands of four to six inches impure rock	5	
		75	8

There are at present two plants using Lower Magnesian limestone in the manufacture of Portland cement; viz., Illinois Hydraulic Cement Company and Utica Hydraulic Cement Company. More detailed information regarding the character and extent of the cement rock has been

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[1] Geology of LaSalle county: Geol. Survey of Ill., Vol. III, pp. 281, 282.

given by G. H. Cady.[1] Although about 100 feet is the maximum thickness exposed, well records show that the formation is about 450 feet thick at the Illinois-Iowa boundary.

ST. PETER SANDSTONE.

Lying next above the Lower Magnesian limestone is the St. Peter sandstone. It is soft, friable, and very porous; and is composed, locally at least, of rounded grains of nearly pure quartz. This formation, although its outcrops are considerably more extensive, is confined to nearly the same counties as the limestone formation below. In LaSalle county the outcrop extends along the Illinois in a belt from 3 to 5 miles wide from Fox river to Vermilion river. It continues 8 or 10 miles up the Fox river, with a small detached area a little farther north; also about 5 miles up the Vermilion; and 15 or more miles up the Little Vermilion. In Ogle county there is a somewhat wider belt bordering Rock river for 5 or 6 miles north of Oregon, nearly to Dixon, and also an outcrop of several square miles in the headwaters of Elkhorn creek. The only remaining exposure is at Cap au Grés bluff in southern Calhoun county. The maximum exposed thickness of the sandstone is only 150 feet, but the maximum thickness shown by well records is 275 feet. The St. Peter sandstone is economically important as a source of abundant water supply from deep wells, and as a material suited for use as glass sand.

"TRENTON-GALENA" LIMESTONE.

The "Trenton-Galena" formation exhibits considerable variation in different portions of the State. In the northwest corner, in JoDaviess county,[2] Bain has divided the formation into two members, Platteville limestone below, and Galena limestone above. The Platteville was formerly called Trenton but is now considered older than the Trenton of New York; the latter corresponding in age more nearly to the Galena. The general section of the Platteville is given by Bain as follows:

Generalized section of the Platteville in northwestern Illinois.

		Feet.
4.	Limestone and shale in thin beds	10 to 20
3.	Limestone, thin bedded, brittle, breaking with concoidal fracture	25 to 30
2.	Magnesian limestone, buff to blue, heavy bedded	20 to 25
1.	Shale, blue	1 to 5

Only No. 4 of the section outcrops in Illinois, and this only in very limited areas north of Galena and at East Dubuque. The shales are commonly blue or green but in some places are yellow, chocolate, or even black. The limestone is generally blue, fine grained, thin bedded, and fossiliferous.

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[1] Cement-making materials in the vicinity of LaSalle: Bull. Ill., State Geol. Survey, No. 9, pp. 118-130.

[2] Bain, H. Foster, Zinc and lead deposits of Northwestern Ill.: Bull. U. S. Geol. Survey No. 246, 1905, pp. 18-21.

The Galena limestone of the same region is a massive dolomite which forms the main ore-bearing rock of the zinc district. As typically developed it is dark buff, granular, and highly crystalline; and when weathered presents deeply pitted and protuberant surfaces. Chert is abundant in the middle portion of the formation and fossils occur at certain horizons. The total thickness is about 240 feet.

While these two formations do not maintain their typical character in an easterly direction, it is still possible to trace the two horizons throughout the area in which the "Trenton-Galena" outcrops in the northern part of the State. This area includes the larger part of JoDaviess county; most of Stephenson, Winnebago, Boone, Ogle, Lee; and also eastern Carroll, northern Bureau and LaSalle, southern DeKalb, and western Kendall. Other limited outcrops occur in Calhoun, Jersey, Monroe, and Alexander counties.

In the Calhoun-Jersey county region the "Galena-Trenton" rocks include three formations,[1] which are, from oldest to youngest, the Joachim, Plattin, and Kimmswick limestones.

The Joachim limestone is a buff, argillaceous, magnesian limestone tending to be thin bedded, and occasionally carrying shale. The formation attains a thickness of 75 feet, and its exposures are confined to a narrow belt just above the St. Peter sandstone. The Plattin limestone is a purer, gray limestone about 100 feet thick, bedded similarly to the Joachim limestone. The limestone is fine grained, hard, dense, and breaks with conchoidal fractures. It is about 100 feet thick. The Kimmswick limestone is light colored or nearly white, coarsely crystalline, and very fossiliferous. This limestone is believed to be a little older than the Trenton of New York. The maximum thickness that has been observed in this region is 50 feet.

In Monroe and Alexander counties exposures of the "Trenton-Galena" formations are confined to small outcrops of Kimmswick limestone similar in character to that in Calhoun and Jersey counties, with a maximum thickness of about 100 feet in Monroe county.

RICHMOND FORMATION.

The uppermost formation in the Cincinnatian series in Indiana and Ohio is termed "Richmond," and although different names have been applied to the Cincinnatian rocks of Illinois, their fauna indicates that they are also of Richmond age. The Richmond formation as represented by the Maquoketa shale in northwestern Illinois is blue or green shale with occasional bands of limestone, and it attains a thickness of approximately 175 feet. In Calhoun and Monroe counties it is a green shale, somewhat dolomitic at the base, and only about 75 feet thick. In Alexander county the formation consists of two members, the uppermost of which is a gray shale containing thin calcareous beds, and the lower or "Thebes sandstone and shale" is a brownish shaly sandstone. The two aggregate about 90 feet in thickness. In northeastern Illinois the Cincinnatian beds occupy a rather narrow belt which extends from

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[1] Weller, Stuart, Geology of southern Calhoun county: Bull. Ill. State Geol. Survey No. 4, p. 222.

southeastern Ford to northwestern McHenry county. The beds here are greenish and bluish, argillaceous to arenaceous shales above, with a limestone bed in the lower part, together having an approximate thickness of 250 feet.

In Indiana and Ohio the Utica and Lorraine formations intervene between the Trenton and Richmond formations. This fact suggests a possible nonconformity in Illinois; which, indeed, is well established. In Calhoun county Weller[1] has described a clear nonconformity at the base of the Richmond; though in northwestern Illinois Bain[2] finds no evidence of one.

SILURIAN SYSTEM.

GIRARDEAU AND EDGEWOOD FORMATIONS.

From carefully studied sections in Alexander county, Savage[3] has designated as "Alexandrian" the Girardeau limestone, and the closely associated limestone and shale immediately above, which constitute the Edgewood formation. The record is as follows:

Section in Alexander county.

		Feet.
3.	Limestone, coarse grained, somewhat oolitic, in layers 12 to 18 inches thick	3½
2.	Limestone and shale, fine grained, dark colored, in layers 8 to 14 inches thick	8½
	(Break in sedimentation).	
1.	Limestone, fine grained, black, brittle, in layers 1 to 4 inches thick, separated by thin lenses or partings of calcareous shale *(Girardeau Limestone)*	33 to 38

Savage considers that this section more or less completely bridges the gap between the Cincinnatian and the Clinton, and that the beds should be placed in the Silurian rather than in the Ordovician.

CLINTON AND NIAGARAN LIMESTONES.

The succeeding rocks of Silurian age in Illinois have long been referred to as the "Niagara limestone." They do not, however, exactly correspond with the Niagara or, as it is now called, the Lockport limestone of New York, but represent a much longer time interval. These rocks occur in several more or less distinctly separated areas which present considerable lithologic variation.

With future detailed study the rocks will probably be separated into more definite formations. The first separation has already been made

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[1] Geology of southern Calhoun county: Bull. Ill. State Geol. Survey No. 4. p. 223.

[2] Zinc and lead deposits of upper Mississippi Valley: Bull. U. S. Geol. Survey No. 294, p. 33.

[3] Ill. State Geol. Survey, Bull. No. 8, p. 110.

in Alexander county where Savage[1] has correlated the Silurian rocks as belonging to the Clinton formation. The composite section of the Clinton limestone as given by Savage is as follows:

Section in Alexander county.

	Feet.
3. Limestone, pink, mottled, in layers 10 to 45 inches thick	23
2. Limestone, layers of gray to drab, 2 to 6 inches thick, alternating with thin bands of chert	6
1. Limestone, tough, gray, in layers 3 to 8 inches thick, imperfectly separated by partings of chert, 2 to 4 inches thick	0 to 46

In Jersey and Calhoun counties and in northwestern Illinois the Niagaran limestone is a fine-grained, somewhat cherty, dolomite. It is 50 to 100 feet thick in the former region and about 150 feet thick in the latter. The widest occurrence of these rocks is in northeastern Illinois, where they extend north from Iroquois county and east from DeKalb and Kendall to the State boundaries. In this region the Niagaran is composed of bluish or buff, massive dolomite.

DEVONIAN SYSTEM.

Most of the rocks of Devonian time in Illinois occupy three limited and widely separated regions. The first of these is in Rock Island county where the rocks have a maximum thickness of about 150 feet, and are mostly limestones of middle and upper Devonian time. The second Devonian area is in Calhoun and Jersey counties where only about 10 to 30 feet of limestone is present. The third area is in Jackson, Union, and Alexander counties where the Devonian attains a thickness of about 735 feet.

While the fauna of the first two areas shows that the beds of these regions are associated with the Iowan province to the west, the fauna of the third shows the rocks of that region to be entirely different, and related to the Devonian of Indiana, Ohio, and New York. The names of the eastern formations therefore apply to these rocks, and will be used in describing them.

HELDERBERG (NEW SCOTLAND).

The New Scotland formation aggregates 160 feet in thickness, the lower 100 feet of which is shaly limestone with interbedded bands of chert, and the upper 60 feet a gray, heavy-bedded, coarsely crystalline limestone. The analysis in the tables of a sample (S57*a*) taken from the upper part of this formation in an old quarry north of Grand Tower in Jackson county, shows that some of this limestone possesses a high degree of purity.

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[1] Savage, T. E., Lower paleozoic stratigraphy of southwestern Ill.: Bull. Ill. State Geol. Survey No. 8, p. 111.

ORISKANY (CLEAR CREEK CHERT).

The Clear Creek chert corresponds with upper Oriskany of New York. This formation is composed of light-gray to yellowish cherts that are commonly in thin layers but which in the lower part are sometimes 3 to 5 feet thick. Their total thickness is about 240 feet. In some places the cherts, where exposed at the surface, are thoroughly leached and decomposed into a fine-grained, unconsolidated mass containing a high percentage of silica. Analyses[1] show from 73.78 per cent to 75.78 per cent of SiO_2. This "silica" is already used to some extent in the arts, and because of its fineness of grain and amorphous character warrants still further development.

ONONDAGA LIMESTONE.

The Onondaga formation, with the exception of about 20 feet of iron-stained sandstone at the base, consists mostly of gray, more or less crystalline limestone aggregating about 160 feet in thickness.

HAMILTON LIMESTONE AND SHALE.

The Hamilton is made up of gray to black limestone, more or less shaly or siliceous in the upper portion, and about 70 feet thick. At the base of the Hamilton in Union county is 28 feet of yellowish blue shale which possibly corresponds to the Marcellus of New York.

OHIO SHALE.

The uppermost Devonian beds are brown to black or greenish shales or siliceous limestones which reach a thickness of about 90 feet. A part of these doubtless are to be correlated with the Ohio shale of Ohio, and the New Albany of Indiana. In Hardin county, in a small area about Hicks, there is an exposure of approximately 50 feet of black fissile shale which is assigned to this horizon.

MISSISSIPPIAN SYSTEM.

In geologic literature Mississippian and Pennsylvanian are generally used to designate series, but here in conformity with recent usage[2] they are used to designate systems. The rocks of the Mississippian period occur in a belt which extends nearly the entire distance from Mercer to Jackson counties in the western part of the State, and through Union, Johnson, Pope, and Hardin counties in the southern part. The Mississippian was divided under the Worthen Survey into the following units, beginning at the bottom: 1. Kinderhook; 2. Burlington; 3. Keokuk; 4. St. Louis; 5. Chester. Weller[3] and others, however, have shown that

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[1] Bain, H. F., Analysis of certain silica deposits: Bull. Ill. State Geol. Survey No. 4, p. 186.

[2] Chamberlin and Salisbury, Geology Vol. II, chaps. 9 and 10. Geology of north-central Wisconsin, p. 6.

[3] The geological map of Illinois: Bull. Ill. State Geol. Survey No. 6, p. 23.

several more divisions should be made. If, however, the Keokuk-Warsaw is separated into two formations, the series from oldest to youngest may be stated as follows:

Mississippian subdivisions.

9. Birdsville-Tribune. } (Chester of
8. Cypress. } some authors).
7. Ste. Genevieve.
6. St. Louis.
5. Salem (Spergen).
4. Warsaw.
3. Keokuk.
2. Burlington.
1. Kinderhook.

KINDERHOOK.

The Kinderhook beds are sandstones, shales, or limestones. The rocks belonging to this formation occur from Henderson to Union counties, although no single member has such wide distribution. The formation varies in thickness from 25 to 200 feet. The sandstones and shales greatly predominate and the limestones are usually impure. The section at Kinderhook as reported by Worthen,[1] although not closely typical for the State, is given as follows:

Section at Kinderhook.

		Feet.
5.	Loess, capping the bluff	20
4.	Limestone (Burlington)	15
3.	Limestone, thin bedded, fine grained	6
2.	Sandstone, thin bedded, and sandy shales	36
1.	Shales, argillaceous and sandy, partly hidden	40

The Kinderhook beds include 1 to 3 of the section and probably about 20 feet more below No. 1.

BURLINGTON LIMESTONE.

The Burlington limestone is typically developed at Burlington, Iowa, and extends more or less continuously from this point to Union county. It is generally highly crystalline and nearly white, although in the northern part of the area it locally contains brownish beds in its lower portions. In places the formation is nearly pure limestone, but as a rule it contains chert in horizontal lenses or layers from 2 to 4 inches thick, which may equal or even exceed the aggregate thickness of the limestone. The maximum thickness of the Burlington is about 200 feet.

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[1] Pike County: Geol. Survey of Ill., Vol. IV, p. 27.

KEOKUK LIMESTONE.

The Keokuk limestone in its typical development at Keokuk, Iowa, is darker than the Burlington limestone and differs from the latter also in having shaly partings which separate the thicker ledges of limestone, and, in some places, become several feet in thickness. At the top of the formation at Warsaw there is a conspicuous geode bed which may be recognized as far south as Jersey county. (The section exposed at Warsaw is given under the description of the Warsaw formation.) The Keokuk limestone is nearly everywhere very cherty but in the type locality is comparatively free from it. Occasional beds are pure enough for use in the manufacture of Portland cement. The total thickness of the formation is about 125 feet.

WARSAW LIMESTONE AND SHALE.

The Warsaw formation, as most recently described by Weller,[1] comprises a series of limestones and shales approximately 30 feet thick. The section exposed in the type locality is as follows:

Geologic section at Warsaw.

		Feet.
	St. Louis.	
11.	Limestone, dense, bluish, brecciated	10
	Salem.	
10.	Limestone, more or less cross bedded, yellow on weathered surfaces and granular in appearance, containing large numbers of broken bryozoans; sometimes replaced by calcareous grit or sandstone	8
	Warsaw.	
9.	Limestone, thin bedded, bluish, interbedded with calcareous shales; fossil bryozoans abundant	18
8.	Shale, fine, blue	3
7.	Limestone, hard, light colored, with few poorly preserved fossils	4
6.	Shale, fine, blue	8
5.	Magnesian limestone with shaly bands; fossils poorly preserved, usually rare, mostly bryozoans	8
	Keokuk.	
4.	Shales, bluish, with numerous geodes which are usually smaller than those in the magnesian limestone beds below	21
3.	Magnesian limestone with chert bands	3
2.	Magnesian limestone with numerous geodes; some beds more or less shaly, geodes most numerous in the middle part of the bed; fossils poorly preserved and rather rare, mostly imperfect bryozoans	15
1.	Limestone, crystalline, blue or gray, with many fossils; extending below river level (exposed)	15

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[1] The Salem limestone: Bull. Ill. State Geol. Survey No. 8, pp. 83-88.

The Keokuk and Warsaw beds are clearly differentiated in the type locality but toward the south the goede beds that mark the top of the Keokuk disappear and it becomes difficult to separate the two formations. The prevailingly argillaceous character of the Warsaw, however, and the more calcareous aspect of the Keokuk holds, generally, as far as Union county.

SALEM LIMESTONE (SPERGEN).

The Salem limestone is present in all the counties containing Mississippian rocks, from Hancock to Union. In the north the formation is only a few feet thick, as shown in the section at Warsaw. Toward the south, however, this gradually increases to a maximum of 125 feet in the southern half of its outcropping area. On the bluffs of the Mississippi east of Piasa creek in Madison county the following section of the Salem formation has been measured by Weller:[1]

Section of Mississippi river bluff east of Piasa creek.

		Feet.
12.	Limestone, thin bedded, very fine in texture, of gray or yellowish color; beds ⅛ to 1 inch thick, almost shale-like in appearance	7
11.	Talus-covered slope	14
10.	Limestone of variable character, some beds more magnesian than others, most beds rather thin but some 1 foot thick; partly covered with talus	10
9.	Limestone, gray or buff, granular, heavy bedded, scaly, weathered surface; fossils abundant	11
8.	Magnesian limestone, fine grained, gray or blue, similar in texture to the cement-bed formerly mined near Clifton	2
7.	Limestone, with coarse, irregular texture; numerous crinoid stems and bryozoans showing on the weathered surface	1
6.	Magnesian limestone, yellowish, impure	1
5.	Limestone, fine grained, granular, gray or yellowish; good fossils not common, although the entire bed is composed of worn organic fragments	12
4.	Limestone, impure, brownish, more or less thin bedded	3
3.	Limestone, crystalline, yellowish, granular, with abundant fossils, of which some are well preserved	4½
2.	Limestone, similar to that above but with fossils less perfectly preserved; occurs in two ledges with a shaly band between	6½
1.	Talus slops with no exposure	25

The beds of the formation vary in character, especially to the north, but as a rule the limestones are comparatively free from chert, and throughout their extent some of them are nearly white and in many places oolitic in texture. The oolitic beds are similar to the famous Bedford limestone of Indiana with which they are correlated. In some places the limestone is magnesian and suited to the manufacture of

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[1] The Salem limestone: Bull. Ill. State Geol. Survey No. 8, p. 91

natural cement, as at Clifton Terrace in Madison county. At Sugarloaf school-house in the western end of St. Clair county an old mine formerly yielded limestone for this purpose. Some of the limestones are pure enough for Portland cement, as shown in the table by the analysis of a sample (C21*b*), taken from an outcrop near Versailles, Brown county.

ST. LOUIS LIMESTONE.

The St. Louis limestone is generally considerably darker than the Salem. The beds vary from comparatively pure limestone to shaly or magnesian limestone and shale, but the formation is particularly characterized by brecciated beds and others of bluish-gray limestone with conchoidal fracture and texture, almost like that of lithographic stone. Brecciated beds are inconspicuous or absent south of St. Louis. The amount of chert is exceedingly variable. In the river bluffs north of Alton but little occurs; in other regions, however, cherty zones are more or less conspicuous, although nowhere so abundant as in parts of the Burlington and Keokuk limestones.

The St. Louis, like the Salem, is only a few feet thick at Warsaw but in the south reaches a thickness of 250 feet or more. A composite section measured by Weller in the quarries and bluffs north of Alton shows the entire thickness of the St. Louis limestone in this region together with portions of the formations above and below it.

Section north of Alton.

Ste. Genevieve.

		Feet.
26.	Sandstone, cross bedded	20
25.	Sandstone, somewhat conglomeritic	6
24.	Sandstone, fine grained, cross bedded	18
23.	Limestone, white	4

St. Louis.

22.	Limestone	7
21.	Limestone, brown, arenaceous	1½
20.	Limestone, with numerous chert bands	20
19.	Limestone, rather heavy bedded, blue	11
18.	Limestone, hard, blue	17
17.	Limestone, thin bedded, shaly partings	5
16.	Limestone, hard, pure, blue, upper 3 feet brown in places	26
15.	Limestone with shaly partings	2
14.	Limestone, hard, blue	8
13.	Limestone, brecciated	19
12.	Limestone, gray to buff, becoming somewhat thin bedded above	22
11.	Limestone, brown	2½
10.	Limestone, dense, gray, with numerous sections of brachiopods on the weathered surface	2
9.	Limestone, in 1-inch layers, gray, locally brownish, ripple-marked surface, 2 feet from bottom	22½

		Feet.
8.	Limestone, heavy bedded below, thinner bedded above (Top of quarry)	17
7.	Limestone, yellow, earthy, probably magnesian...	4
6.	Limestone, impure, thick and thin beds, some shaly layers; 6 inches of blue, clay shale at base. Towards the top the beds become thicker, hard, dense limestone	13
5.	Limestone, impure, very cherty, somewhat earthy, yellowish, probably magnesian	13
4.	Magnesian (?) limestone, shaly below	3
3.	Limestone, dense, cherty	5
2.	Limestone, similar to that below, but more dense, a little darker, with some hard masses and chert	8

Salem.

1.	Limestone, light gray, granular, with abundant fossils in pockets and bands; no chert	18

Nos. 2 to 12 of the section represent the exposure in the quarry of the Blue Grass Crusher Company; Nos. 13 to 17 in the Armstrong quarry; and Nos. 18 to 22 in the quarry of the Alton Lime and Cement Company and the Watson quarry. The purest limestones of the St. Louis formation occur in the portion represented by Nos. 13 to 22 of the section.

At a number of localities samples of the St. Louis limestone have been collected and analyzed by the Survey, and most of them prove to be good Portland-cement material. Some of the analyses are found in later tables under Nos. C 34, 37, and 40.

STE. GENEVIEVE LIMESTONE.

The Ste. Genevieve limestone closely resembles the St. Louis, and formerly was not separated from it. In this formation, however, there appears a recurrence to a notable extent of the oolitic phase and of the fossils of the Salem limestone. The base of the Ste. Genevieve is so similar to the St. Louis that it is not everywhere possible to draw a sharp line between them. In Monroe county at least the two formations are easily differentiated.

On the Ohio river at Fairview Point in Hardin county an outcrop of the upper beds of the formation was measured by Weller as follows:

Section at Fairview Point.

		Feet.
6.	Limestone and shale, not exposed, limestone ledge at bottom	42
5.	Limestone and shale, not well exposed	15
4.	Limestone	8
3.	Shale, fossiliferous	7
2.	Limestone	29
1.	Sandstone (Rosiclare)	16

The analysis of a composite sample of all the limestone exposed is shown in the table as W 330.

CYPRESS SANDSTONE.

The Cypress sandstone is a fine-grained, yellowish-brown sandstone, rather thinly bedded above. Its base is the dividing plane between the lower or calcareous portion of the Mississippian and the upper, with prevailing arenaceous beds. The formation is present in St. Clair, Monroe, and Randolph counties, and again in Union, Johnson, Pope, and Hardin counties. Its thickness varies from about 75 to 150 feet. It is barren of cement-making material.

BIRDSVILLE AND TRIBUNE FORMATIONS.

The Birdsville and Tribune are composed of an alternating series of three limestones and three sandstones or shales with a total thickness of about 500 feet. The name "Chester" has been commonly applied to these formations but is now reserved for the larger unit comprising these beds and the underlying Cypress sandstone; the Ste. Genevieve may ultimately be included also.

The Birdsville and Tribune as a whole are prevailingly arenaceous, the limestones forming only one-fifth to one-third of their thickness. With the limestones, however, shale beds are associated in such proportions as to furnish material suited to Portland-cement manufacture. The limestones reach their maximum development in the Chester region. A section measured by Weller in the river bluff near Menard is as follows:

Section near Menard.

		Feet.
9.	Shale beds, exposed more or less continuously in bank of creek	17
8.	Limestone, with occasional cherty bands	27
7.	Limestone ledges	27
6.	Shales, exposed more or less continuously	43
5.	Limestone ledges, more or less thin bedded	7
4.	More or less talus covered, probably shale or shaly beds	32
3.	Talus covered	12
2.	Limestone	60
1.	Limestone talus	40

Analyses giving the composition of the limestones numbered 2 and 8 in the section are shown in the later table as W 208 and 209. As shown by the analyses these limestones would make good Portland-cement material, and probably a correct mixture could be made by the addition of shale from the same section. The favorable stripping conditions and convenience of transportation suggests this location as favorable for a cement plant.

Another promising location in this same formation is at Limestone Hill, west of Golconda, in Pope county. On the Illinois Central railroad at this point is an exposure of 100 feet or more of limestone and shale. Analyses of the limestone are given in a later table as W 319 and 321.

PENNSYLVANIAN SYSTEM.

The formations of the Pennsylvanian epoch are the surface rocks everywhere except in the extreme south and in the counties for which the lower formations have been already described. They contain all the coal-bearing rocks in the State, many of the known oil pools, practically all of the fire clays, most of the paving-brick shales, and some of the purest limestones. Despite the great economic importance of these rocks much geological work needs to be done in correlating the beds. The limestones are important horizon markers and are economically important but occur as comparatively thin and infrequent beds.

As stated several times in these reports, the First Geological Survey numbered the Illinois coals, beginning with No. 1 at the bottom and including No. 16 at the top. While, for the most part, the correlations were correct from place to place, a number of serious errors were made, so that it is no longer desirable to use numbers except in a local sense. Similarly, the Pennsylvanian rocks were early divided at the Carlinville limestones into Upper and Lower "Coal Measures," but this division has ceased to be useful. In order to determine the best horizon-markers and the most useful formation units for Illinois, Indiana, and Kentucky, which comprise the Eastern Interior Coal Basin, correlation studies have been made during the last four years, particularly by Mr. David White of the U. S. Geological Survey. He has determined by means of fossil plants that the rocks below the Murphysboro coal (Coal No. 2) belong to the same age as those which are called "Pottsville" in the east. Furthermore, those over this coal reaching up to and including the Herrin coal (No. 6), and probably No. 7 of the Danville area, correspond in age with the Allegheny formation. Presumably the rocks higher than No. 6 or No. 7 are post-Allegheny, but the division line has not yet been determined.

The formation units and names now adopted in coöperation by the State Geological Survey and the U. S. Geological Survey are referred to in ascending order, as follows:

POTTSVILLE FORMATION.

The lowest Pennsylvania rocks, extending up to the base of the Murphysboro coal (No. 2, Colchester, or "Third Vein" coal), are prevailingly sandy in character and correspond to the Pottsville formation of the East. In the western and northwestern portions of the Pennsylvanian area in Illinois the Pottsville includes, commonly, one coal and a few feet of limestone, clay, shale, and sandstone, which rest unconformably upon the Mississippian. In the southern part of the State, however, the Pottsville rocks are as much as 700 feet thick[1] and include a number of thin coals. The limestone at the top of the Pottsville occurs in the western counties as lenses, bowlders, or extended beds sometimes 15 feet or more thick. This limestone lies immediately above or locally in the stoneware clays of this region.

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[1] DeWolf, Frank W., Studies of Illinois Coal: Bull. Ill. State Geol. Survey No. 16, p 179.

CARBONDALE FORMATION.

Overlying the basal formation and extending from the bottom of the Murphysboro Coal (No. 2) to the top of the Herrin Coal (No. 6 or No. 7 locally), occurs a series of shale, sandstone, coal, and limestone, comprising the Carbondale formation. This combines the units for which was proposed the names "LaSalle" and "Petersburg." The formation is 200 to 240 feet thick in the LaSalle region but 285 to possibly 460 feet in southern counties. It contains no limestone of importance for cement manufacture.

MCCLEANSBORO FORMATION.

The Pennsylvanian rocks overlying the Herrin coal (No. 6) form the McLeansboro formation and have a maximum thickness in southeastern Illinois of about 1,000 feet. From 275 to 350 feet above the Herrin coal is a limestone of considerable stratigraphic importance. It is known in Illinois as the Carlinville[1] limestone and was considered by Worthen to be the dividing line between the "Lower Coal Measures" containing the thick coals, and the "Upper Coal Measures" containing the thin coals. Outcrops of this limestone have been traced from LaSalle to the southeast to a point near where the Wabash river enters Illinois, and to the southwest to Carlinville in Macoupin county, and thence to Nashville in Washington county. The limestone is compact and hard, breaking into splintery pieces, and is generally bluish-gray or brownish when weathered. It tends to weather into beds 2½ or 3 inches thick. The maximum thickness of the bed is only about 7 feet so that its economic value is limited to local use.

The important limestone of the Pennsylvanian, occurring just below the Carlinville, is the LaSalle limestone, and is at present the only bed in the State that is being used with shale in the manufacture of Portland cement. The occurrence of this limestone in the vicinity of LaSalle has already been described and mapped by G. H. Cady.[2] On Mr. Cady's map the limestone is shown to occur in a narrow belt paralleling the Little Vermilion and Vermilion rivers from about four miles north of LaSalle to a point a little south of Bailey's Falls. LaSalle itself is situated on the limestone, which also extends some distance west toward Peru. The typical LaSalle limestone is blue-gray to light-cream color, compact, and has a rather straight fracture. Weathering gives the rock a fragmentary appearance and causes the upper harder portion to overhang the lower softer portion. This feature is responsible for the cascade at Bailey's Falls. The Limestone varies between 20 and 30 feet thick. Between the two beds is a calcareous shale that is from 8 inches to 3½ feet thick.

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[1] A discussion of the various other names applied to this limestone is given by Jon Udden, notes on the Shoal Creek limestone: Bull. Ill. State Geol. Survey No. 8, pp. 118-129.

[2] Cement making materials in the vicinity of LaSalle: Bull. Ill. State Geol. Survey No. 8, pp. 130-134.

A section in the quarry of the Chicago Portland Cement Company is given below, and analyses of beds 1, 4, and 5 are shown in later tables under E 6, *e, b,* and *a.*

Section of quarry of Chicago Portland Cement Company.

		Feet.
5.	Limestone, hard, grey (E 6*a*)	6 to 20
4.	Limestone, argillaceous, weathering into shaly chips (E 6*b*)	4 to 6
3.	Limestone, sandy, separated into layers by thin shale bands	2
2.	Coal, slaty	1
1.	Shale, blue-gray (E 6*e*)	5 to 6

Another important Pennsylvanian limestone outcrops over an area of less than two square miles near Fairmount in Vermilion county. This is used with slag by the Universal Portland Cement Company in the manufacture of Portland cement.

CRETACEOUS SYSTEM.

The Cretaceous system is, according to a recent survey,[1] represented in Illinois by the Ripley formation in Pulaski, Massac, and Pope counties. The beds are all unconsolidated sands and clays ranging from 20 to 40 feet thick, and lying unconformably upon the Paleozoic formations.

TERTIARY SYSTEM.

The Tertiary rocks belong to the Porters Creek, Lagrange, and Lafayette formations. The rocks are similar to those of the Cretaceous formations and occur in the same counties. Their thickness is approximately 150 feet.

QUATERNARY SYSTEM.

Throughout the greater portion of the State the older rocks are more or less deeply covered by glacial deposits. The driftless areas are confined to portions of JoDaviess, Stephenson, Carroll, and southern Calhoun counties and to the counties south of the ridge which extends from Grand Tower on the Mississippi to Elizabethtown on the Ohio. The Pleistocene deposits consist of unstratified glacial till, stratified sand and gravel, loess, and alluvium. The drift in southern Illinois is commonly not more than 30 feet thick, but in the northern part of the State it is in places 150 feet or more in thickness.

SUMMARY.

In the stratigraphic succession of rocks in Illinois from oldest to youngest, the limestones becomes less and less prominent. Limestone comprises nearly one-half of the total thickness of the Ordovician, all

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[1] Glenn, L. C., Underground Waters of Tenn. and Ky U. S. G. S. Water Supply and Irrigation Paper No. 164, pl. 1.

of the Silurian, and considerable portions of the Devonian and Mississippian rocks; but in the Pennsylvanian limestones are inconspicuous. The Ordovician and Silurian limestones, however, are mostly magnesian, and not suited to Portland-cement manufacture. These rocks occupy all the northern counties in the State. The Devonian rocks contain calcareous limestones but they occupy very limited areas in the west and south. The Mississippian limestones have a good average purity, and outcrop extensively in the western and southern counties. The Pennsylvanian limestones are usually thin and only locally developed, but some of the local occurrences, notably at LaSalle and Fairmount, are of much economic importance.

CHAPTER V—DESCRIPTION OF LOCALITIES FROM WHICH LIMESTONE SAMPLES WERE COLLECTED.

(Compiled by E. F. Lines.)

INTRODUCTION.

The letters appearing in the sample numbers are initials of members of the Survey, and indicate the geologists who collected the samples and described their occurrence. The key to the letters is as follows: B=H. F. Bain; Bu=E. F. Burchard; C=G. H. Cady; D=F. W. DeWolf; E=A. J. Ellis; S=T. E. Savage; U=Jon Udden; W=Stuart Weller.

Samples which are shown by the chemical analyses to be suited for use in the manufacture of Portland cement are marked with an asterisk (*) here and in the summary, Table I.

ADAMS COUNTY.

C 15. Location: West side sec. 11, T. 2 S., R. 9 W. Geological formation, *Burlington*. Sample taken from quarry in southern part of Quincy, just north of Wabash Junction. Limestone very flinty. There are a number of quarries along the river bluff which expose rock as much as 30 feet thick.

C 16.* Location: SW. ¼, sec. 26, T. 1 S., R. 9 W. Geological formation, *Keokuk*. Sample of a flinty, fossiliferous limestone taken from river bluff north of Quincy.

C 17.* Location: NW. ¼, sec. 11, T. 1 N., R. 7 W. Geological formation, *Salem*. Sample taken from a 3-foot outcrop of thin-bedded, fossiliferous limestone, 5 miles east of Mendon. This occurs below an outcrop of St. Louis limestone, and is underlain by blue clay.

ALEXANDER COUNTY.

D 42.* Location: Sec. 17, T. 15 S., R. 3 W. Geological formation, *Kimmswick*. Sample taken from 35-foot outcrop in river bluff one-half mile south of Thebes. The outcrop is about 300 yards long and could probably be worked with moderate stripping from the west end of the bluff to the north and northwest, but the available quantity of stone has not been determined.

BROWN COUNTY.

C 18.* Location: SE. cor. sec. 6, T. 2 S., R. 3 W. Geological formation, *Salem.* Sample from 3-foot exposure in Dry Ford creek, 5 miles south of Mount Sterling. The hill here rises steeply above the stream but offers fair stripping conditions. A generalized section from exposures within one-fourth mile along the stream is as follows:

Section along Dry Ford creek.

		Feet.
5.	Limestone, hard, gray, compact, unfossiliferous, non-flinty, breaking with a nearly conchoidal fracture (C 18)	3
4.	Clay, blue	1½
3.	Dolomite, silicious, good quarry-stone	4½
2.	Dolomite, shaly, greenish white	1
1.	Dolomite, buff, silicious	5

C 19, *a, b, c.** Location: NW. ¼ sec. 18, T. 2 S., R. 3 W. Geological formation, *Salem.* Samples taken at or near quarry on land of Joseph Merservey, 7 miles south of Mount Sterling. Stripping conditions are rather favorable, and apparently there is a good deal of rock. Measurements are as follows:

Section 7 miles south of Mount Sterling.

		Feet.
3.	Limestone, compact, silicious, buff, non-flinty, and unfossiliferous (C 19*a*)	4
2.	Limestone, gray, subcrystalline, rather silicious, the silica appearing in fine grains (C 19*b*)	4½
1.	Dolomite, fine grained; the upper 4 feet becomes fossiliferous limestone toward the north (C 19*c**)	20

C 20. Location: NW. ¼, sec. 26, T. 2 S., R. 3 W. Geological formation, *Salem.* Sample taken in ravine 3 miles southwest of Versailles:

Section near Versailles.

		Feet.
5.	Limestone, thin bedded, fossiliferous, somewhat silicious in bands (C 20)	10 to 15
4.	Dolomite, buff	4
3.	Dolomite, silicious; and shale	8
2.	Dolomite, buff, rather coarse grained	4
1.	Clay, blue, with hard, thin-bedded, fossiliferous limestone at bottom	5 to 10

C 21, *b.** Location: NW. ¼, SE. ¼, sec. 20, T. 2 S., R. 3 W. Geological formation, *Salem.* Sample from outcrop in Surratt Hollow, 6 miles west of Versailles. For about 1 mile along McGee creek, and running about one-half mile up both sides of the ravine known as Surratt Hollow is an outcrop of about 10 feet of very pure limestone, On the Elijah Surratt farm the exposure is as follows:

Section 6 miles west of Versailles.

		Feet.
4.	Shale, "Coal measures"	4
3.	Limestone, hard, compact, unfossiliferous, rather silicious	2
2.	Conglomerate, quartz and limestone	1
1.	Limestone, thin bedded, very fossiliferous (C 21*b**)	9

C 22.* Location: Sec. 17, T. 2 S., R. 3 W. Geological formation, *Salem.* Sample from a quarry on the farm of L. M. Surratt, Surratt Hollow.

C 23.* Location: Sec. 18, T. 2 S., R. 3 W. Geological formation, *Salem.* Sample taken from last northern exposure in Surratt Hollow.

C 24.* Location: NE. ¼, sec. 20, T. 2 S., R. 3 W. Geological formation, *Salem.* Sample from road outcrop.

C 25. Location: NE. ¼, SE. ¼, sec. 3, T. 2 S., R. 2 W. Geological formation, *Salem.* Sample taken from 3-foot exposure along the road 3½ miles northeast of Versailles. The limestone varies from subcrystalline, thin bedded, to fine grained, rather silicious. Along the adjacent stream about 8 feet of silicious dolomite of a lower horizon is exposed, but no limestone shows above.

C 26. Location: SE. cor. sec. 15, T. 1 N., R. 2 W. Geological formation, *Salem.* Sample taken from 5-foot exposure in the bed of a small stream on the west side of the road between Ripley and Cooperstown. The limestone is overlain by a ferruginous "Coal Measures" sandstone. There is considerable limestone in this immediate locality, mostly in the heads of the ravines. The "Coal Measures" strata and drift usually overlie it. Stripping conditions are fair.

C 27.* Location: SE. ¼, SE. ¼, sec. 15, T. 1 N., R. 2 W. Geological formation, *Salem* and *St. Louis.* Sample taken from outcrop in east branch of creek about 1 mile north of Cooperstown. Stripping conditions are rather favorable. A general section of exposures along the stream is as follows:

Section 1 mile north of Cooperstown.

		Feet.
7.	Limestone, fine grained, brecciated, non-flinty, unfossiliferous	3
6.	Limestone, fine grained, buff, silicious	1
5.	Limestone, hard, compact, bluish, much like that found at top	4
4.	Clay, blue	½
3.	Limestone, silicious and argillaceous	8
2.	Dolomite, bluish	8
1.	Dolomite, buff	8

Sample includes 5 to 7 of section.

C 28.* Location: SW. ¼, sec. 4, T. 1 N., R. 2 W. Geological formation, *St. Louis.* Sample taken on Logan creek, east of the bridge on Ripley-Cooperstown road. Stripping conditions are rather favorable, the limestone ledge being near the top of the hill.

Section on Logan creek.

		Feet.
6.	Fire clay	
5.	Sandstone	1
4.	Limestone, hard, compact, fine textured, unfossiliferous, non-flinty, and of conchoidal fracture	1
3.	Limestone, yellowish, silicious, fine grained, non-flinty, unfossiliferous	½
2.	Limestone breccia, (limestone pieces like No. 4)	6
1.	Dolomite, silicious, argillaceous, bluish, intercalated with blue clay	7

Sample includes Nos. 2, 3, and 4 of section.

BUREAU COUNTY.

C 11, *a*, *b*. Location: SW. ¼, NE. ¼, sec. 33, T. 16 N., R. 11 E. Geological formation, *McLeansboro (LaSalle limestone)*. Sample taken from outcrop in gully west of Spring Valley.

Section near Spring Valley.

		Feet.
6.	Limestone, fine grained, irregular bedded, lower 3 feet fossiliferous (C 11*a*)	8
5.	Shale, blue, compact	2½
4.	Shale, hard, almost limestone	2
3.	Shale, black or dark blue	2
2.	Limestone, fossiliferous, crinoidal, gray	1
1.	Shale, black, compact	4

A little to the southwest of the above outcrop a quarry shows 8 feet of fine-grained, compact, hard, grayish limestone which breaks into sharp pieces, and contains some fossils (C 11, *b*). It belongs above No. 5 of section.

E 15, *a*, *b*.* Location: Sec. 31, T. 16 N., R. 11 E. Geological formation, *McLeansboro (LaSalle limestone)*. Sample taken from exposure in bed of small creek just east of Marquette.

Section near Marquette.

		Feet.
4.	Limestone, light blue, containing few fossils (E 15*a*)	7½
3.	Shale, blue (E 15*b**)	7
2.	Limestone, impure, sandy and shaly	1
1.	Shale	

CLARK COUNTY.

S 9.* Location: NE. ¼, sec. 28, T. 10 N., R. 14 W. Geological formation, *McLeansboro (Quarry Creek limestone)*. Sample taken from quarry 2½ miles southeast of Casey. This limestone outcrops up the creek from the quarry for nearly a mile, with an aggregate thickness of 20 to 28 feet.

Section near Casey.

		Feet.
3.	Limestone, hard, gray, containing numerous fossils and having a rough, splintery fracture	2½
2.	Limestone, thin layers, (1 to 3 inches), very hard, gray, with partings of shale	4
1.	Limestone, hard, gray, shelly, with rough, hackly fracture, in 12- to 36-inch layers	8½

S 51, *a*,* *c*.* Location: NW. ¼, sec. 6, T. 11 N., R. 11 W. Geological formation, *McLeansboro (Quarry Creek limestone)*. Samples were taken from quarry near new concrete bridge of the Big Four railroad across Big creek. The crushed stone for the concrete of the bridge was taken from this quarry.

Section on Big creek.

		Feet.
3.	Limestone, brittle, gray, fossiliferous, imperfectly separated into irregular 1- to 2-inch layers for about two feet from the top; the rest massive, with very rough fracture (S 51*a**)	8
2.	Shale, bluish gray, without fossils	4¼
1.	Limestone, hard, gray, subcrystalline, with few shells, in imperfect layers 18 to 24 inches thick (S 51*c**)	5¾

S 52, *a,** *b.** Location: NW. ¼, sec. 29, T. 11 N., R. 11 W. Geological formation, *McLeansboro.* Sample taken in Frederick Stump's quarry, 2 miles east and 1 mile south of Marshall.

Section southeast of Marshall.

		Feet.
3.	Limestone, hard, gray, showing imperfect layers 8 to 14 inches thick (S 52*a**)	5
2.	Limestone, hard, gray, in imperfect layers 4 to 12 inches thick (S 52*b**)	5½
1.	Nodular calcareous layers 1 to 3 inches thick, alternating with bands of gray shale 2 to 4 inches thick, the lowermost 12 inches being a true shale.	4
	Some rods west of this quarry layers of hard gray limestone outcrop to about 6 feet above No. 3 of section.	

COLES COUNTY.

S 3.* Location: NW. ¼, sec. 5, T. 12 N., R. 10 E. Geological formation, *McLeansboro.* Sample taken from 18-foot exposure near Charleston. There are large quantities of this limestone situated favorably for quarrying.

EDGAR COUNTY.

Bu 2.* Location: NE. ¼, sec. 3, T. 15 N., R. 12 W. Geological formation, *McLeansboro.* Sample taken from old quarry on property of David Tucker and George Triplet, three-fourths mile southwest of Cherry Point. The limestone is brittle, fine grained, and streaked with calcite. The outcrop is in the former bed of Bruellette creek, which was filled with water when visited. The rock is exposed in Bruellette creek and appears to dip slightly southwest. It is reported to be 12 feet thick where not thinned by erosion, but is only 5 feet thick at one end of the quarry. There is said to be 15 acres of rock still available, under an overburden of 8 to 20 feet, mainly of soil and clay.

S 50, *a,** *c.** Location: SE. ¼ of NE. ¼, sec. 10, T. 14 N., R. 11 W., 1 mile east of Baldwinsville. Geological formation, *McLeansboro.*

Section near Baldwinsville.

		Feet.
4.	Limestone, hard, gray, subcrystalline, fossiliferous, weathering into very rough-surfaced layers 2 to 4 inches thick, and breaking with rough, hackly fracture (S 50*a**)	5 to 7
3.	Shale, gray or bluish gray; in the lower half are bands of limestone 1 to 2 inches thick, between layers of shale of about the same thickness	3½ to 4
2.	Limestone, hard, bluish gray, in 8- to 18-inch layers, weathering into imperfect layers 2 to 5 inches thick (S 50*c**)	6
1.	Shale, grayish, exposed	2

The fossils and section of this limestone are similar to those of the Charleston limestone in Coles county.

HANCOCK COUNTY.

C 38. Location: Sec. 30, T. 5 N., R. 8 W. Geological formation, *Keokuk.* Sample taken from a small quarry about one-half mile north of railroad station at Hamilton where the street car line turns up the bluff. The exposure shows about 9 feet of flinty limestone, the upper 4½ feet of which is somewhat argillaceous and less flinty.

C 40.* Location: NW. ¼, sec. 14, T. 7 N., R. 8 W. Geological formation, *St. Louis.* Sample from a 10-foot outcrop of St. Louis conglomerate in a gully near Niota. In places the bed is rather regular, and the conglomeratic character not evident. The rock is very fine grained, even textured, hard and unfossiliferous. Where the bed is conglomeratic the gray limestone is mixed with a buff dolomite, the pieces being broken roughly and cemented by an argillaceous cement, which looks much like the buff dolomite. Flint occurs with the dolomite and limestone. The sample represents 6 feet of an even-bedded portion of the limestone. Below the limestone is a green, silicious shale of varying hardness.

C 41.* Location: SE. ¼, sec. 16, T. 7 N., R. 8 W. Geological formation, *Keokuk.* Sample taken from a 4-foot outcrop about one-fourth mile west of the iron bridge south of Niota on the Prairie road to Nauvoo. The limestone is hardly thick enough for practical use.

C 42. Location: SE. cor. sec. 12, T. 6 N., R. 8 W. Geological formation, *Keokuk.* Sample taken in a ravine about 2 miles south of Nauvoo, where the river road goes up to the prairie. At the mouth of the ravine an outcrop of very flinty limestone occurs in a cliff about 30 feet high. About one-half mile up the ravine is an outcrop of a geode bed which is underlain by 5 feet of almost non-flinty limestone, from which the sample was taken.

HARDIN COUNTY.

W 322. Location: SW. ¼, sec. 27, T. 12 S., R. 8 E. Geological formation, *St. Louis.* Sample taken from quarry at mouth of Big creek, Jacks Point, about one-half mile below Elizabethtown. About 50 feet of limestone is exposed in the quarry.

W 330.* Location: SW. ¼, sec. 5, T. 13 S., R. 8 E. Geological formation, *Ste. Genevieve.*

Section along Ohio river at Fairview Point.

		Feet.
8.	Sandstone, cypress	40
7.	Limestone and shale not exposed	42
6.	Limestone ledge	
5.	Limestone and shale not well exposed	15
4.	Limestone	8
3.	Shale, fossiliferous	7
2.	Limestone	29
1.	Sandstone, Rosiclare	16

Sample is a composite of all the limestones in the section.

HENDERSON COUNTY.

C 39.* Location: Sec. 22, T. 8 N., R. 6 W. Lomax, Ill. Geological formation, *Burlington or Keokuk.* Sample taken from a few small outcrops along the bed of the ravine southeast of the house on farm of C. E. Lowry. Some stone for building has been taken from here, but the quarry has since caved in and no longer offers a good exposure. No flints were found in this place, but in the bed of the ravine there were many that probably came from the limestone. The outcrop is overlain by about 75 feet of loess.

JACKSON COUNTY.

S 5, *x.** Location: NE. ¼, sec. 25, T. 10 S., R 4 W. Geological formation, *Onondaga.* Sample taken from an abandoned quarry about one block south of the railway station at Grand Tower. About 15 feet of limestone, in ½- to 1½-foot layers is exposed with no overburden. Sample represents the entire exposure.

S 57, *a.** Location: NW. ¼, sec. 25, T. 10 S., R. 4 W. Geological formation, *New Scotland.* South end of Devil's Backbone, Jackson township. Sample taken from an old quarry a short distance north of the coal switch at Grand Tower.

Section near Grand Tower.

		Feet.
2.	Chert layers 2 to 4 inches thick	20
1.	Limestone, gray, subcrystalline, somewhat crinoidal, and fossiliferous in the upper half (S. 57, *a**)	48

JOHNSON COUNTY.

D 16,* 17.* Location: Sec. 1, T. 14 S., R. 2 E., on Big Four railroad near Belknap. Geological formation, *Ste. Genevieve.*

Section at Belknap.

		Feet.
8.	Sandstone	25
7.	Unexposed	5
6.	Limestone, coarse (D 16*)	18
5.	Unexposed; showing both limestone and sandstone debris	20
4.	Limestone; coarse, compact and oolite varieties; old quarry (D 17*)	15
3.	Sandstone, calcareous	18
2.	Limestone	15
1.	Concealed to railroad	25

W 304.* Location: SW. ¼, sec. 5, T. 14 S., R. 2 E., in Cache River bluff 5 miles west of Belknap. Geological formation, *Ste. Genevieve.*

Section along Cache river.

		Feet.
5.	Sandstone	10
4.	Limestone	53
3.	Limestone, oolitic	2
2.	Limestone	5
1.	Talus slope, perhaps underlaid by limestone	55

Sample includes 2 to 4 of section.

W 308.* Location: Middle of W. ½, sec. 16, T. 13 S., R. 3 E. Geological formation, *"Chester."* Sample taken from a limestone exposure of 30 feet or more. The top of the hill is capped with heavy ledges of sandstone. The limestone was formerly quarried and burned for lime.

LA SALLE COUNTY.

C 2, *a,* c,* d.** Location: Sec. 15, T. 33 N., R. 3 E. Geological formation, *McLeansboro (LaSalle limestone).* Samples taken from quarry of German-American Portland Cement Company. (See also E 1, *a, b, c.*)

(1) Section of quarry of German-American Portland Cement Co.

		Feet.
4.	Limestone, fine grained, crystalline, thin and loosely bedded (C 2*a**)	5
3.	Clay, bluish gray	3
2.	Limestone, thin bedded, gray, crystalline (C 2*c**)	6
1.	Limestone, somewhat heavier bedded, bluish, fine grained, semi-crystalline (C 2*d**)	4

Under 1 of section, but not quarried, is a hard, black clay bed.

C 3, *a,* b,* d.** Location: Sec. 6, T. 32 N., R. 2 E. Geological formation, *McLeansboro (LaSalle limestone).* Sample taken from mine of Marquette Portland Cement Company, one-half mile south of Deer Park.

Section near Deer Park.

		Feet.
8.	Limestone, compact, crystalline (C 3*a**)	6
7.	Parting; the roof of most of the mine	
6.	Limestone, compact, crystalline (C 3*b**)	6
5.	Clay, bluish gray	1
4.	Limestone, crystalline (C 3*d**)	6
3.	Parting; floor of most of the mine	
2.	Limestone, white	2
1.	Clay, black, hard, containing a 3-inch seam of coal	10

No. 1 of section used for clay supply.

C 9.* Location: NW. ¼, sec. 11, T. 33 N., R. 1 E. Geological formation, *McLeansboro (LaSalle limestone).* Sample taken from limestone ledge along Little Vermilion river one-half mile north of LaSalle. Stripping conditions are excellent.

Section along Little Vermilion river.

		Feet.
7.	Limestone, fossiliferous	4
6.	Clay and limestone in thin beds, fossiliferous	6
5.	Limestone, non-fossiliferous	1½
4.	Clay and limestone, non-fossiliferous	½
3.	Limestone, heavy bedded, compact	5
2.	Limestone, thin bedded, clayey	5
1.	Clay, blue	

Sample is composite of all the limestone in the section.

C 10.* Location: SE. ¼, sec. 34, T. 34 N., R. 1 E. Geological formation, *McLeansboro (LaSalle limestone.)* Sample taken from an outcrop in a gully at LaSalle. This is the northernmost good outcrop of limestone on Little Vermilion river. It is along the west bluff and has an overburden of 5 to 10 feet of drift.

Section at LaSalle.

		Feet.
4.	Limestone, thin bedded, mixed with clay	5½
3.	Clay and fossiliferous limestone	2
2.	Limestone, heavy bedded, unfossiliferous	8
1.	Limestone and clay with few fossils	4

Sample includes 1 to 4.

C 12, *a,* b.* Location: Near center sec. 6, T. 32 N., R. 2 E. Geological formation, *McLeansboro (LaSalle limestone).* Sample taken from limestone ledge at Bailey's Falls, south of LaSalle. The limestone dips to the west and disappears about one-half mile east of the falls.

Section at Bailey's Falls.

		Feet.
3.	Limestone, hard, gray, massive, weathering thin bedded (C 12*a**)	10
2.	Clay and fossiliferous limestone	2½
1.	Limestone (C 12*b*)	4

C 13. Location: SW. ¼, sec. 30, T. 33 N., R. 1 E. Geological formation, *McLeansboro (LaSalle limestone).* Sample taken from exposure in a gully in the south bluff of Illinois river west of Peru.

Section along Illinois river.

		Feet.
3.	Limestone, ferruginous; and pebble conglomerate ..	2
2.	Clay, light bluish green, calcareous	2
1.	Limestone, bluish green, with considerable clay (C 13)	4

C 14, *a, b.* Location: SW. cor. sec. 8, T. 33 N., R. 2 E. Geological formation, *Lower Magnesian limestone.* Sample taken from quarry of the Illinois Hydraulic Cement Manufacturing Company, west of Utica. The limestone used for cement comes from two beds. The upper one is 6 to 8 feet thick (C 14, *a*); and the lower, 22 feet below, is 12 to 14 feet thick (C 14, *b*).

E 1, *a,* b, c.* Location: SE. ¼, NW. ¼, sec. 14, T. 33 N., R. 1 E. Geological formation, *McLeansboro (LaSalle limestone).* Sample from quarry of the German-American Portland Cement Company, LaSalle. (See also C 2, *a, c, d.*)

(2) Section in quarry of German-American Portland Cement Company.

		Feet.
4.	Limestone, hard, gray, in places crinoidal, and also bearing numerous other fossils (E 1*a*)	6½
3.	Shale, bluish gray, without fossils (E 1*b*)	3½
2.	Limestone, gray, argillaceous in places, and imperfectly separated by thin bands of shale into 3- to 12-inch layers (E 1*c*)	6½
1.	Limestone, argillaceous, gray, weathering into small shaly chips (E 1*d*)	5

E 3. Location: Utica. Geological formation, *Lower Magnesian limestone.* Sample taken from quarry car at plant of Illinois Hydraulic Cement Company.

E 6, *a,* b.** Location: SE. ¼, sec. 25, T. 33 N., R. 1 E. Geological formation, *McLeansboro (LaSalle limestone).* Sample taken from quarry of Chicago Portland Cement Company, one-half mile northeast of Oglesby on Vermilion river.

Section near Oglesby.

		Feet.
5.	Limestone, hard, gray, non-fossiliferous (E 6*a**)	6 to 20
4.	Limestone, argillaceous, weathering into shaly chips; contains fossils (E 6*b**)	4 to 6
3.	Limestone, sandy, separated into layers by shale partings	2
2.	Coal, slaty	1
1.	Shale, bluish gray (E 6*e*)	5 to 6

LEE COUNTY.

C 5, *a*,* *b*.* Location: SW. ¼, sec. 27, T. 22 N., R. 9 E. Geological formation, *Platteville*. Sample from quarry of Sandusky Cement Company, Dixon. The cement materials are taken from the beds that were sampled. (See, also, S 46, *c*,* *d*, *e*.*)

Section at Dixon.

		Feet.
3.	Limestone, thin bedded, bluish, fossiliferous (C 5*a**)	5
2.	Dolomite, fine grained, yellowish	6
1.	Limestone, bluish, compact, fossiliferous, in beds ½ to 1½ feet thick (C 5*b**)	8

C 6. Location: NE. ¼, sec. 18, T. 22 N., R. 9 E. Geological formation, *Platteville*. Sample taken by road 4 miles north of Dixon.

(1) Section north of Dixon.

		Feet.
3.	Dolomite, flinty, fine grained, compact, subcrystalline	4
2.	Limestone, variably bedded, with an occasional clay seam	5
1.	Limestone, heavy bedded, buff-blue (C 6)	7

S 46, *c*,* *d*, *e*.* Location: Sec. 27, T. 22 N., R. 9 E. Geological formation, *Platteville*. Sample from quarry of Sandusky Portland Cement Company. (See, also, C 5, *a*,* *b*.*)

(2) Section north of Dixon.

		Feet.
5.	Clay, yellow, with some sand	4 to 7
4.	Gravel	2 to 3
3.	Limestone, gray, fossiliferous, in about 1-inch layers (S 46*c**)	4 to 6
2.	Limestone, light gray, with imperfect layers 3 to 9 inches thick, with a 4-inch shale band at top (S 46*d**)	10
1.	Limestone, bluish gray, fine grained, very hard, fossiliferous, in about 8- to 16-inch layers (S 46*e**)	9

LOGAN COUNTY.

E 28, *a*,* *b*. Location: Near NW. cor. sec. 5, T. 19 N., R. 3 W., near Lincoln. Geological formation, *McLeansboro*. The limestone is not exposed but comes within 3 feet of the surface. It has been quarried but the hole is now filled. The section reported by the owner of the land is as follows:

Section near Lincoln.

		Feet.
4.	Limestone, shelly (E 28*a**)	2
3.	Limestone, hard, gray, in 10- to 24-inch layers (E 29*b*)	6
2.	Shale, blue	3
1.	Limestone, hard, gray	10

MARSHALL COUNTY.

E 20, *b*. Location: SW. ½, NW. ¼, sec. 14, T. 12 N., R. 9 E. Geological formation, *Pennsylvanian.* Sample from outcrop on south side of road about one-fourth mile west of Sparland. The exposure is at the bottom of the bluff, which rises 100 feet and is capped by limestone. The rest of the bluff is apparently yellowish shale.

Section near Sparland.

		Feet.
5.	Clay, yellowish	2 to 5
4.	Limestone, soft, argillaceous, fossiliferous, weathering into shaly chips (E 20*b*)	4 to 6
3.	Clay, bluish above and yellowish below	10
2.	Sandstone in thin slabs	3 to 4
1.	Shale, fine, blue	3+

E 23.* Location: SE. ¼, sec. 14, T. 12 N., R. 9 E. Geological formation, *Pennsylvanian.* Sample from old stone quarry on west side of Sparland. This pit has supplied stone for local purposes, though idle when visited. The limestone sampled is 2 to 3 feet thick and lies along the surface of the bluff. It is nodular and resembles closely the Craddock stone at Pontiac.

MONTGOMERY COUNTY.

694,* 698.* Location: Hillsboro, Ill. Geological formation, *McLeansboro* of the Pennsylvanian. The analyses were made at suggestion of Mr. Josiah Bixler of Hillsboro, and are assumed to be representative of the rock in the neighborhood. The first sample is understood to represent an exposure along the creek in sec. 32, T. 9 N., R. 4 W., and the second, a 20-foot exposure, one-eighth mile north of Quarry, sec. 2, T. 8 N., R. 5 W.

OGLE COUNTY.

C 7, *a*. Location: SE. ¼, sec. 27, T. 23 N., R. 9 E. Geological formation, *Platteville.*. Sample from outcrop on west bank of Pine creek 9 miles southwest of Oregon.

Section along Pine creek.

		Feet.
7.	Limestone, thin bedded, non-flinty, and with no fossils (C 7*a*)	10
6.	Dolomite, hard, compact, buff, non-flinty, unfossiliferous, thick bedded	11
5.	Shale, brown	½
4.	Clay, blue, with dark layers	1½
3.	Clay, reddish	½
2.	Clay, blue, becoming sandy and yellow at bottom	4
1.	Sandstone	2

The section is at the contact of the St. Peter and Trenton formations.

C 8. Location: NW. ¼, sec. 28, T. 24 N., R. 10 E. Geological formation, *Platteville.* Sample from outcrop along stream 2 miles north of Oregon.

Section near Oregon.

		Feet.
2.	Limestone, fossiliferous, thin bedded, light brown (C 8)	10
1.	Dolomite, heavy bedded, hard, reddish, "buff beds"	8

At the base of the outcrop is a line of large springs.

PEORIA COUNTY.

Bu 8.* Location: SE. ¼, sec. 5, T. 11 N., R. 7 E. Geological formation, *McLeansboro (Maxwell limestone).* Sample taken from quarry on property of Fred Streitmatter near Princeville. (See, also, E 26.*)

Section near Princeville.

		Feet.
3.	Soil	3
2.	Limestone, fine grained, argillaceous and silicious, in layers from ½ inch thick at top to 4 inches thick at bottom, and in the more weathered portion much broken vertically into fragments or "chip rock"	12
1.	Limestone, coarse grained, grayish, containing calcite crystals and fossils, exposed	1½

No. 1 is reported to be 4 to 5 feet thick and underlain by clay shale containing thin coal. From 12 to 14 feet of rock has been quarried at four or five places within a distance of one-half mile in sections 4 and 5. At each of three places in these sections, at least 20 acres of rock from 10 to 12 feet thick underlies less than 10 feet of cover. (See, also, E 26.*)

Bu 9.* Location: SE. cor. sec. 10, T. 8 N., R. 7 E. Geological formation, *McLeansboro (Maxwell limestone).* Samples from outcrop on property of George Swords, 1 mile east of Maxwell. Occasional outcrops for one-half mile high on the banks of a small creek expose 10- to 12-foot beds of gray, brittle, medium-grained, and partly argillaceous limestone. This underlies the northern part of Limestone township and the southwestern part of Kickapoo township. The overburden, which is soil and loess-like clay, varies from 3 to 30 feet; but where sample was obtained 3 to 4 acres, or possibly more, can probably be worked with moderate stripping.

(1) Section in Swords quarry.

		Feet.
6.	Limestone, greenish gray, argillaceous, partly concretionary, weathered so that it breaks in chips 1 to 3 inches across; exposed (higher layers probably concealed)	4

		Feet.
5.	Limestone, light gray, fine grained, hard and brittle, with thin streaks and particles of calcite and a few fossils	2
4.	Limestone, hard, gray, medium grained, with considerable calcite and some fossils. Splits easily along bedding planes into layers 4 to 8 inches thick	2½
3.	Concealed interval	1
2.	Limestone, somewhat like top layers, though not so completely fractured and not so argillaceous, but becoming shaly towards bottom; exposed	5
1.	Shale, bluish black, containing thin seam of carbonaceous material about 2 feet below top; exposed	12

Sample includes Nos. 2 to 6, equivalent to a composite of the three samples next described.

E 24, *a*, *b*, *c*.* Location: SE. ¼, sec. 10, T. 8 N., R. 7 E. Geological formation, *McLeansboro (Maxwell limestone)*. Sample from above described quarry owned by George Swords. The section sampled has but a foot or two of sandy soil stripping.

(2) Section in Swords quarry.

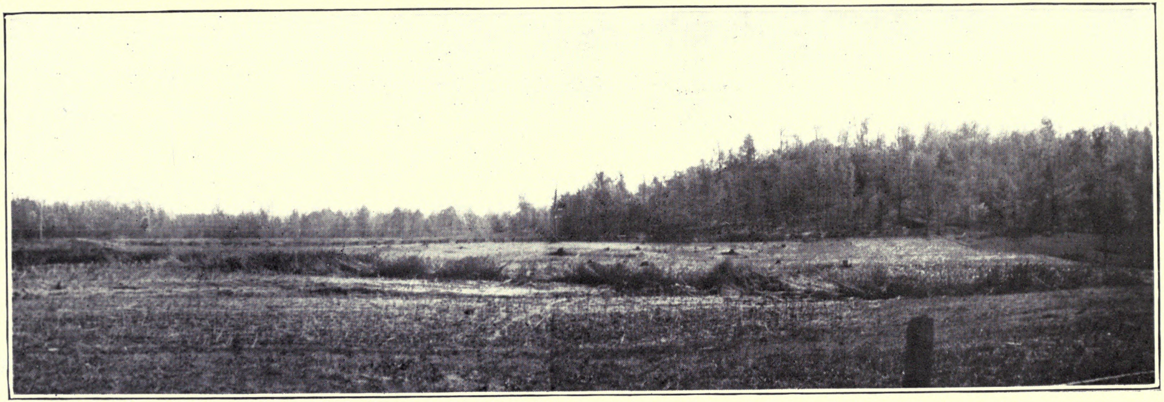
		Feet.
6.	Limestone, loose, white nodular (E 24*a*)	3 to 4
5.	Limestone, gray, containing fossils (E 24*b*)	6 to 7
4.	Same as No. 5, but evenly bedded, used for building (E 24*c**)	3
3.	Shale, gray	½
2.	Shale, black slaty, bituminous, nearly coal at some exposures	5
1.	Shale, gray	20

E 26.* Location: SE. ¼, sec. 5, T. 11 N., R. 7 E. Geological formation, *Pennsylvanian*. Sample taken from a 10-foot exposure in a quarry on west side of road, 3 miles northeast of Princeville. The limestone is very white and almost non-fossiliferous. The upper part is weathered into slabs, though not in a distinct zone, while the lowermost foot or two is more regularly bedded in layers about 10 inches thick. The ledge is underlain by a good bed of coal which lies at the surface in many of the valleys. (See, also, Bu 8.*)

POPE COUNTY.

D 48.* Location: NE. ¼, sec. 31, T. 13 S., R. 5 E. Geological formation, *"Chester."* Sample from a 32-foot outcrop on the Whittenberg farm on Big Bay creek, one-half mile east of Reevesville. Sampled about every foot except at two concealed intervals of 2 feet.

W 311.* Location: Sec. 31, T. 13 S., R. 5 E. Geological formation, *"Chester."* About 50 feet of limestone is exposed in beds from 6 inches to 2 feet thick with somewhat shaly partings, and occasionally containing a small amount of chert. This sample is from the same property as D 48.*



Limestone Hill, west of Golconda.

W 319.* Location: Sec. 19, T. 13 S., R. 7 E. Geological formation, *"Chester."* Sample from quarry on hillside north of Golconda to right of road going up hill. At this point about 15 feet of limestone has been quarried and crushed for road making. Above the limestone and also below it are shaly beds.

W 320. Location: SW. ¼, SE. ¼, sec. 22, T. 11 S., R. 7 E. Rainey place, 14 miles north of Golconda. Geological formation, *Ste. Genevieve.* Sample from prospect pit for spar.

Section on Rainey farm.

		Feet.
2.	Shale	10
1.	Limestone with shale partings (W 320)	15

W 321.* Location: Sec. 26, T. 13 S., R. 6 E. Geological formation, *"Chester."* Sample from outcrop on property of Edward B. Clark, Limestone Hill, west of Golconda and one-fourth mile northwest of the Illinois Central railroad. (See Plate XVIII.) The outcrop of 100 feet or more of limestone and shale is so covered with talus that the proportions of limestone and shale cannot be seen. The sample was taken from one of the outcropping beds of limestone.

Bu 20.* Location: Sec. 26, T. 13 S., R. 6 E. Geological formation, *"Chester."* Sample is composite of all outcropping limestone beds in the same section from which sample W 321* was taken. The sample represents an aggregate of 50 feet or more of limestone. The overburden is light. The analyses of samples of shale from the same locality, as given in a later chapter, indicate that the materials are well adapted for cement manufacture.

PULASKI COUNTY.

D 47.* Location: Sec. 14, T. 14 S., R. 1 W. Geological formation, *St. Louis.* Sample from old quarry near Ullin. The section shows 60 feet of limestone overlain by thin layers of clay and gravel. Sample represents the lower 40 feet. The old quarry face is about 400 yards long and from 25 to 60 feet high. Formerly, a spur connected it with the Illinois Central railroad, and the rock was used for railroad ballast and for concrete.

RANDOLPH COUNTY.

B 6.* Location: Sec. 23, T. 7 S., R. 7 W. Geological formation, *"Chester."* Sample taken from outcrop north of prison grounds at Menard.

B 8.* Location: Sec. 23, T. 7 S., R. 7 W. Geological formation, *"Chester."* Sample taken from the quarry of the Southern Illinois Penitentiary at Menard.

U 47.* Location: Sec. 20, T. 5 S., R. 9 W. Geological formation, *St. Louis.* Sample from F. M. Brickley's place in Prairie du Rocher. There is an exposure here of about 75 feet of limestone.

W 208,* 209.* Location: NW. ¼, sec. 15, T. 7 S., R. 7 W. Geological formation, *"Chester."* Samples taken from outcrops along the river bluff at Menard.

Section at Menard.

		Feet.
9.	Shale, exposed more or less continuously in bank of creek	17
8.	Limestone with occasional cherty bands (W 209*)	27
7.	Limestone ledges	27
6.	Shales, exposed more or less continuously (W*a** and *b**)	43
5.	Limestone ledges, more or less thin bedded	7
4.	Talus covered, probably shale or shaly beds	32
3.	Talus covered	12
2.	Limestone (Menard) (W 208*)	60
1.	Limestone talus	40

Two samples of shale collected by Elmer Grant from the horizon of No. 6 of the section in the same vicinity gave results as shown by the table of clay analyses under W, *a** and *b*.*

W 253.* Location: SW. ¼, sec. 5, T. 4 S., R. 8 W. Geological formation, *"Chester."* Sample from Red Bud city quarry, including 8 to 12 feet of blue limestone.

W 254.* Location: NW. ¼, sec. 4, T. 4 S., R. 8 W. Geological formation, *"Chester."* Sample from William's quarry, Red Bud. This is nearly white limestone, probably 8 feet in thickness.

ROCK ISLAND COUNTY.

Bu 15,* 16.* Location: Sec. 25, T. 17 N., R. 1 W. Geological formation, *Hamilton.* Sample taken from outcrops in the bluffs of Mill creek, southeast of Milan. The limestone is exposed in the creek bed 1¼ miles southeast of Milan, between the Chicago, Rock Island, and Pacific railroad and the bluffs bordering the flood plain. Where the creek cuts its way through the upland before reaching the flood plain there are several good exposures of shaly, jointed beds, and of the heavier quarry ledges below the shaly part. Both members are very fossiliferous. Sample Bu 15* was taken from the east bluff of Mill creek, about one-fourth mile from the escarpment. Twenty feet of limestone are exposed, the upper 5 feet of which is shelly, crinoidal limestone, and the lower 15 feet shaly and jointed limestone containing many brachiopods. Sample Bu 16* was taken about one-eighth mile north of Bu 15*, from a 7- to 8-foot exposure on the north bluff of the creek just west of the place where it reaches the flood plain of Rock river. This is a fossiliferous limestone, with some calcite crystals. The beds are thick but include a little shaly material at the top.

SCHUYLER COUNTY.

C 30.* Location: SE. ¼, sec. 29, T. 1 N., R. 2 W. Geological formation, *Salem* or *St. Louis*. Sample taken from the east bank of Crooked creek north of Ripley, where an old quarry exposes about 4 feet of limestone. There is no definite ledge but the outcrop is in pieces; below which lies a heavy dolomite.

C 31.* Location: NW. cor. sec. 19, T. 1 N., R. 2 W. Geological formation, *Salem* or *St. Louis*. Sample taken from Crooked creek, between Ripley and Scott's Mill. A ledge of limestone about 5 feet thick on each side of the creek extends probably one-half mile down the creek, and is underlain by a bed of dolomite.

C 32. Location: NW. ¼, sec. 7, T. 1 N., R. 2 W. Geological formation, *Salem* or *St. Louis*. Sample taken in a gully beside the road to Scott Mill about 4 miles east of the mill. Pennsylvanian rocks overlie the limestone, making stripping conditions unfavorable.

Section east of Scott Mill.

		Feet.
4.	Conglomerate, partly limestone and partly buff dolomite	5
3.	Dolomite, fine grained, bluish to buff, somewhat nodular	2
2.	Limestone, subcrystalline, irregularly bedded	1
1.	Limestone, shaly, grayish, fine grained, becoming sandy and argillaceous toward the bottom	5

Sample includes 2 to 4 of section.

C 34.* Location: SW. cor. sec. 34, T. 2 N., R. 3 W. Geological formation, *St. Louis*. Sample from farm of Henry Hickman, 4 miles south of Camden. There is here an exposure of 8 feet of conglomeritic limestone containing considerable dolomite. It is found under a red ochre deposit.

C 35, *a*,* *b*. Location: NW. ¼, sec. 17, T. 2 N., R. 3 W. Geological formation, *Keokuk*. Samples from outcrops north of Camden along Cedar creek. C 35, *a** was taken just east of the upper bridge, and C 35, *b*, one-half mile down stream. The latter location exposes limestone 10 to 12 feet thick, rather heavy bedded and fossiliferous, but weathering into thin slabs. Numerous geodes occur above, in a clay soil. The interval from the top of the limestone to the "Coal Measure" sandstone above, measures about 50 feet and is largely filled with silicious clays and argillaceous dolomite.

C 36.* Location: NW. ¼, sec. 11, T. 2 N., R. 3 W. Geological formation, *Salem* or *St. Louis*. Sample taken south of road about 4 miles east of Camden, in a gully tributary to Spring creek. The outcrop here is not very extensive, but there are indications of considerable limestone in the vicinity. Lime was burned here at one time. The limestone is directly overlain by "Coal Measure" sandstone.

C 37.* Location: SW. ¼, sec. 27, T. 3 N., R. 3 W. Southeast of Brooklyn. Geological formation, *St. Louis.* Sample taken from top of bluff in a deep ravine on east side of Crooked creek.

Section along Crooked creek.

		Feet.
4.	Limestone, silicious, broken into small, sharp fragments (C 37*)	8 to 10
3.	Dolomite, irregularly bedded, very uneven, shattered; and silicious shale	15
2.	Shale, gray, silicious	8 to 10
1.	Limestone, argillaceous, geodiferous	4

C 43. Location: Near center NE. ¼, sec. 28, T. 2 N., R. 2 W. Near Rushville. Geological formation, *Pennsylvanian.*

Section near Rushville.

		Feet.
3.	Shale, gray	15
2.	Limestone, hard, dark colored, unfossiliferous, non-flinty, and breaking with conchoidal fracture...	4
1.	Shale, carbonaceous	3

C 45.* Location: NW. ¼, NE. ¼, sec. 5, T. 1 N., R. 1 E. Geological formation, *Pennsylvanian.* Sample from outcrop on Sugar creek north of Frederick. A ledge and a good many blocks of limestone outcrop 50 feet above the base of the hill, along the creek. The rock is gray, non-flinty, non-fossiliferous, and rather rough in appearance. It is about 8 feet thick and continues for about one-fourth mile along the bluff between the two side ravines, without a great thickness of covering. The St. Louis limestone outcrops in places, about 50 feet below.

C 46.* Location: NW. ¼, SW. ¼, sec. 32, T. 2 N., R. 1 E. Geological formation, *Pennsylvanian.* Sample is from the same horizon as C 45*, but was taken about one-half mile farther north. The rock apparently has its normal thickness of about 15 feet, and presents favorable stripping conditions except under a slope in the hill behind the outcrop, where there is 30 to 40 feet of covering.

ST. CLAIR COUNTY.

U 49, *a.** Location: NW. ¼, NE. ¼, sec. 23, T. 1 S., R. 10 W. Geological formation, *St. Louis.* Sample from quarry near Columbia. The limestone in the quarry varies from 30 to 40 feet in thickness. The upper 7 feet contains irregular chert beds.

STARK COUNTY.

E 27, *a*, *b*.* Location: SW. ¼, SE. ¼, sec. 21, T. 14 N., R. 7 E. Geological formation, *Pennsylvanian*. Sample from quarry that recently furnished stone for building and paving.

Section in Stark county.

		Feet.
2.	Limestone, impure, nodular, not compact but mixed with much shale (C 27*a*)	4
1.	Limestone, hard, massive, light colored in places, containing few fossils, and breaking with conchoidal fracture (C 27*b**)	5

STEPHENSON COUNTY.

C 1, *a*. Location: NW. ¼, SE. ¼, sec. 22, T. 29 N., R. 6 E. Geological formation, *Platteville*. Sample from Winslow city quarry. The quarry rock ranges from lower Galena to the blue rock of the Platteville formation.

Section at Winslow.

		Feet.
7.	Soil	1
6.	Dolomite, thin bedded, coarse grained	3
5.	Limestone, thin bedded, blue, and dark shale	5
4.	Limestone, compact, hard, flinty (C 1*a*)	2
3.	Dolomite, thin bedded, fossiliferous	13
2.	Dolomite, thin bedded, fine grained	6½
1.	Dolomite, thick bedded, bluish to buff	12

C 1, *b*, *c*, *d*, *e*. Location: Sec. 22, T. 29 N., R. 6 E. Geological formation, *Platteville*. Sample from quarry 1 mile north of Winslow on Pecatonica river. The section here is practically the same as at Winslow quarry and samples C 1, *b*, *c*, *e* were taken from beds corresponding to 1, 2, 3, and 4 of section given for Winslow.

UNION COUNTY.

D 2. Location: SE. ¼, sec. 17, T. 12 S., R. 1 W. Geological formation, *Salem*. Sample taken from quarry of Swan Creek Phosphate Company at Anna (now Union Stone and Lime Co.). The limestone from which the sample was taken underlies the region for several miles in the vicinity of the quarry. Twenty feet of limestone is exposed but drillings show the stone to be 40 feet thick.

U 66.* Location: Sec. 17, T. 12 S., R. 1 W. Geological formation, *Salem*. Sample from quarry of Union Stone and Lime Company, Anna, Ill.

Section near Anna.

		Feet.
3.	Limestone, oolitic	15
2.	Limestone, hard, gray	22
1.	Chert	8

W 285.* Location: NE. ¼, SE. ¼, sec. 1, T. 13 S., R. 2 W. Geological formation, *Burlington*. Sample from exposure one-eighth mile from Korndahl station on the Mobile and Ohio railroad.

Section near Korndahl station.

		Feet.
2.	Limestone, having a few scattered chert nodules in the lower few feet and very few fossils (W 285*)	40
1.	Shale, rather fissile, siliceous (W 286)	40

The analysis of the shale (W 286) is given with other clay analysis in the later table.

W 291. Location: NW. ¼, sec. 11, T. 12 S., R. 2 W. Geological formation, *Burlington*. Sample taken from a former quarry about one-fourth mile east of the Mobile and Ohio railroad, on a creek. The limestone is free from chert, and conditions for quarrying are favorable. About one-fourth mile west of the limestone is a large body of shale. This limestone sample was lost and the analysis therefore is not found in the table.

Table I. Analyses of limestones.

Samples marked (*) are considered suitable for Portland-cement manufacture.

County.	Sample number.	Loss on ignition.	Silica (SiO_2).	Iron oxide (Fe_2O_3); alumina (Al_2O_3).	Lime (CaO).	Magnesia (MgO).	Water at 105°C.	Silica (SiO_2).	Iron oxide (Fe_2O_3), alumina (Al_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
Adams	C 15	35.10	19.78	1.94	43.42	.84	.30	19.78	1.94	77.47	1.76
Adams	C 16*	39.90	9.66	1.54	48.38	.68	.26	9.66	1.54	86.32	1.42
Adams	C 17*	37.24	12.26	3.92	44.46	.94	.23	12.26	3.92	79.33	1.96
Alexander	D 42*	....	.27	.32	66.25	.48	....	.27	.32	99.77	1.18
Brown	C 18*	42.70	2.96	1.46	52.90	.64	.16	2.96	1.46	94.39	1.34
Brown	C 19*a*	30.84	26.46	10.36	24.30	8.88	.22	26.46	10.36	43.36	18.56
Brown	C 19*b*	14.76	56.64	10.80	16.74	.68	.39	56.64	10.80	29.87	1.42
Brown	C 19*c**	40.10	7.26	2.40	50.10	.38	.15	7.26	2.40	89.39	.79
Brown	C 20	35.98	16.90	3.06	43.88	.54	.31	16.90	3.06	78.30	1.13
Brown	C 21*b**	36.40	15.40	3.10	45.32	.50	.40	15.40	3.10	80.86	1.05
Brown	C 22*	37.26	13.54	3.10	46.16	.56	.07	13.54	3.10	82.36	1.17
Brown	C 23*	39.62	8.78	2.40	48.66	.60	.18	8.78	2.40	86.82	1.25
Brown	C 24*	40.74	6.44	1.90	50.54	.60	.16	6.44	1.90	90.18	1.25
Brown	C 25	42.20	5.80	3.98	39.00	9.60	.33	5.80	3.98	69.59	20.07
Brown	C 26	40.04	8.36	3.92	44.22	3.74	.26	8.36	3.92	78.90	7.81
Brown	C 27*	40.82	6.62	2.64	49.00	1.44	.20	6.62	2.64	87.43	3.01
Brown	C 28*	41.02	5.86	2.42	49.82	1.20	.23	5.86	2.42	88.89	2.51
Bureau	C 11*a*	29.56	26.18	11.00	28.82	5.34	.22	26.18	11.00	51.42	11.16
Bureau	C 11*b*	32.78	22.76	11.10	31.20	2.82	.41	22.76	11.10	55.67	5.89
Bureau	E 15*a*	32.38	23.30	8.64	33.86	2.96	.46	23.30	8.64	60.42	6.19
Clark	S 9*	41.92	4.04	2.94	51.26	.66	.17	4.04	2.94	91.46	1.38
Clark	S 51*a**	43.18	1.74	2.26	52.94	.53	.14	1.74	2.26	94.46	1.11
Clark	S 51*c**	43.16	2.12	1.56	53.24	.69	.08	2.12	1.56	95.00	1.44
Clark	S 52*a**	43.16	1.46	1.62	53.86	.55	.03	1.46	1.62	96.10	1.15
Clark	S 52*b**	40.78	6.26	5.50	46.02	1.96	.22	6.26	5.50	82.11	4.10
Coles	S 3*	....	3.91	1.56	62.20	1.00	....	3.91	1.56	93.67	2.46
Edgar	Bu 2*	42.00	2.66	2.34	51.90	1.42	.22	2.66	2.34	92.62	2.97
Edgar	S 50*a**	43.18	1.52	1.74	53.78	.58	.04	1.52	1.74	95.96	1.21
Edgar	S 50*c**	38.98	8.02	5.52	46.30	1.35	.25	8.02	5.52	82.61	2.82

Table I—Continued.

County.	Sample number.	Loss on ignition.	Silica (SiO_2).	Iron oxide (Fe_2O_3), alumina (Al_2O_3).	Lime (CaO).	Magnesia (MgO).	Water at 105°C.	Silica (SiO_2).	Iron oxide (Fe_2O_3), alumina (Al_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
Hancock	C 38	33.40	23.24	3.34	38.76	2.00	.28	23.24	3.34	69.16	4.18
Hancock	C 40*	42.48	2.62	1.48	53.62	.38	.13	2.62	1.48	95.67	.79
Hancock	C 41*	38.94	10.20	2.36	48.24	.58	.24	10.20	2.36	86.08	1.21
Hancock	C 42	35.98	16.24	3.80	41.84	2.50	.28	16.24	3.80	74.66	5.23
Hardin	W 322	40.18	9.10	2.14	45.08	3.62	.18	9.10	2.14	80.43	7.56
Hardin	W 330*	39.72	7.78	4.10	48.10	1.06	.33	7.78	4.10	85.82	2.21
Henderson	C 39*	43.06	2.30	1.12	54.20	.34	.08	2.30	1.12	96.71	.71
Jackson	S 5*	42.62	3.08	1.12	52.24	1.26	.14	3.08	1.12	93.21	2.63
Jackson	S 57*a**	43.92	.86	.72	52.64	2.34	.07	.86	.72	93.93	4.89
Johnson	D 16*	....	6.00	1.32	59.87	1.75	....	6.00	1.32	90.17	4.33
Johnson	D 17*	....	5.33	.83	61.84	.96	....	5.33	.83	93.11	2.37
Johnson	W 304*	43.34	2.04	1.22	52.72	1.50	.12	2.04	1.22	94.07	3.14
Johnson	W 308*	43.20	.96	1.76	53.56	.74	.11	.96	1.76	95.57	1.55
LaSalle	C 2*a**	42.06	2.88	2.24	51.78	.69	.14	2.88	2.24	92.39	1.44
LaSalle	C 2*c**	39.26	8.78	4.76	46.08	1.96	.15	8.78	4.76	82.22	4.10
LaSalle	C 2*d**	37.88	10.34	4.40	45.58	1.38	.80	10.34	4.40	81.33	2.88
LaSalle	C 3*a**	42.66	1.98	1.56	53.32	.75	.12	1.98	1.56	95.14	1.57
LaSalle	C 3*b**	39.48	7.94	4.80	48.02	.68	.28	7.94	4.80	85.68	1.42
LaSalle	C 3*d**	38.90	8.24	3.40	47.72	1.31	.25	8.24	3.40	85.15	2.74
LaSalle	C 9*	40.20	6.72	5.92	47.84	.66	.12	6.72	5.92	85.36	1.38
LaSalle	C 10*	37.38	11.10	7.84	43.46	1.16	.24	11.10	7.84	77.55	2.42
LaSalle	C 12*a**	42.66	2.66	1.90	52.32	.58	.14	2.66	1.90	93.36	1.21
LaSalle	C 12*b*	35.58	15.24	7.58	41.54	1.14	.49	15.24	7.58	74.12	2.38
LaSalle	C 13	32.14	21.18	16.36	25.02	6.30	.47	21.18	16.36	44.64	13.17
LaSalle	C 14*a*	38.54	15.02	8.20	25.40	12.50	.33	15.02	8.20	45.32	26.13
LaSalle	C 14*b*	38.80	14.42	11.34	26.12	9.82	.12	14.42	11.34	46.61	20.53
LaSalle	E 1*a**	41.06	4.92	3.08	50.52	.89	.17	4.92	3.08	90.14	1.86
LaSalle	E 1*c*	33.28	22.26	6.86	36.62	1.91	.50	22.26	6.86	65.34	3.99
LaSalle	E 1*d*	34.36	17.76	9.56	36.64	2.42	.57	17.76	9.56	65.38	5.06
LaSalle	E 3	44.92	4.58	3.72	28.36	18.30	.11	4.58	3.72	50.60	38.25
LaSalle	E 6*a**	41.92	4.32	2.86	51.32	.59	.16	4.32	2.86	91.57	1.23
LaSalle	E 6*b**	39.16	9.62	5.56	46.08	.74	.38	9.62	5.56	82.22	1.55

Lee	C	*5a**	40.68	5.52	3.66	49.62	.68	.20	5.52	3.66	88.54	1.42
Lee	C	*5b**	41.70	3.44	3.88	48.92	1.98	.16	3.44	3.88	87.29	4.14
Lee	C	6	43.72	4.50	4.60	36.98	11.22	.11	4.50	4.60	65.98	23.45
Lee	S	*46c**	40.54	7.56	3.54	48.48	.60	.09	7.56	3.54	86.50	1.25
Lee	S	*46d*	41.94	5.10	2.58	45.84	4.58	.25	5.10	2.58	81.79	9.57
Lee	S	*46e**	41.92	4.78	4.44	47.04	2.40	.14	4.78	4.44	83.93	5.02
Logan	E	*28a**	41.86	4.70	2.66	50.60	.82	.11	4.70	2.66	90.28	1.71
Logan	E	*28b*	42.84	2.04	4.92	46.96	4.28	.16	2.04	4.92	83.79	8.95
Marshall	E	*20b*	27.74	31.74	8.92	31.26	.88	.65	31.74	8.92	55.78	1.84
Marshall	E	23*	41.38	3.42	2.36	51.76	.72	.22	3.42	2.36	92.36	1.50
Montgomery		694*	42.98	1.41	2.29	53.15	.85	.13	1.41	2.29	94.84	1.78
Montgomery		698*	42.26	2.06	3.45	52.42	1.03	.16	2.06	3.45	93.53	2.15
Ogle	C	*7a*	43.98	1.38	1.56	48.40	5.46	.19	1.38	1.56	86.36	11.41
Ogle	C	8	43.90	5.62	4.22	28.72	16.42	.33	5.62	4.22	51.25	34.32
Peoria	Bu	8*	37.94	13.36	3.24	46.74	.42	.14	13.36	3.24	83.40	.88
Peoria	Bu	9*	36.70	14.24	3.98	45.30	.46	.23	14.24	3.98	80.83	.96
Peoria	E	*24a*	32.88	21.96	5.88	39.26	.48	.48	21.96	5.88	70.05	1.00
Peoria	E	*24b*	33.70	21.04	3.70	41.38	.56	.25	21.04	3.70	73.83	1.17
Peoria	E	*24c**	42.70	2.78	1.82	51.52	1.86	.12	2.78	1.82	91.93	3.89
Peoria	E	26*	35.92	16.46	3.30	44.18	.50	.26	16.46	3.30	78.83	1.05
Pope	D	48*		10.45	1.14	48.88	1.28		10.45	1.14	87.32	2.65
Pope	W	311*	40.08	7.90	2.74	49.16	1.18	.27	7.90	2.74	87.72	2.47
Pope	W	319*	40.46	7.04	2.36	48.44	1.60	.42	7.04	2.36	86.43	3.34
Pope	W	320	33.72	18.06	8.86	39.52	.84	.73	18.06	8.86	70.52	1.76
Pope	W	321*	40.92	5.44	2.90	50.34	1.00	.11	5.44	2.90	89.82	2.09
Pope	Bu	20*	39.85	7.66	2.02	49.74	.93	.21	7.66	2.02	88.75	3.68
Pulaski	D	47		6.39	.49	61.68	.92		6.39	.49	92.90	2.27
Randolph	B	6*		2.48	1.11	62.50	1.56		2.48	1.11	93.95	3.86
Randolph	B	8*		1.90	.67	63.55	1.30		1.90	.67	95.72	3.22
Randolph	U	47*	43.98	.58	.56	54.84	.66	.28	.58	.56	97.85	1.38
Randolph	W	208*	43.08	1.85	1.28	53.45	.69	.22	1.85	1.28	95.37	1.44
Randolph	W	209*	39.00	9.62	1.94	48.27	.68	.16	9.62	1.94	86.13	1.42
Randolph	W	253*	41.26	4.54	5.12	45.82	3.64	.69	4.54	5.12	81.76	7.61
Randolph	W	254*	42.72	1.50	2.00	54.04	.52	.13	1.50	2.00	96.42	1.09
Rock Island	Bu	15*	40.00	6.98	4.32	45.98	2.64		6.98	4.32	82.04	5.52
Rock Island	Bu	16*	43.38	1.66	1.16	54.18	.58		1.66	1.16	96.67	1.21
Schuyler	C	30*	41.46	4.14	1.88	51.86	.66	.22	4.14	1.88	92.53	1.38
Schuyler	C	31*	37.76	11.88	3.84	46.46	.48	.24	11.88	3.84	82.90	1.00
Schuyler	C	32	35.66	15.04	6.44	42.46	1.34	.18	15.04	6.44	75.76	2.80
Schunler	C	34*	42.04	4.14	3.08	49.70	2.24	.14	4.14	3.08	88.68	4.68

Table I—Concluded.

County.	Sample number.	Loss on ignition.	Silica (SiO_2).	Iron oxide (Fe_2O_3); alumina (Al_2O_3).	Lime (CaO).	Magnesia (MgO).	Water at 105°C.	Silica (SiO_2).	Iron oxide (Fe_2O_3), alumina (Al_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
Schuyler	C 35*a**	38.84	9.30	4.54	47.98	.42	.49	9.30	4.54	85.61	.88
Schuyler	C 35*b*	36.92	15.80	5.88	36.00	6.84	.30	15.80	5.88	64.23	14.30
Schuyler	C 36*	38.06	11.30	6.16	43.22	2.72	.25	11.30	6.16	77.11	5.68
Schuyler	C 37	40.66	6.58	2.70	50.60	.42	.24	6.58	2.70	90.29	.88
Schuyler	C 43	33.82	18.62	7.24	39.34	1.72	.26	18.62	7.24	70.19	3.59
Schuyler	C 45*	42.48	2.66	2.18	53.42	.44	.14	2.66	2.18	95.32	.92
Schuyler	C 46*	42.22	3.10	2.14	53.12	.44	.24	3.10	2.14	94.78	.92
St. Clair	U 49*a**	41.16	5.42	2.24	50.32	1.26	.34	5.42	2.24	89.79	2.63
Stark	E 27*a*	29.66	27.24	7.58	35.28	.98	.78	27.24	7.58	62.95	2.05
Stark	E 27*b**	36.38	15.40	2.80	44.52	.72	.29	15.40	2.80	79.44	1.50
Stephenson	C 1*a*	40.78	14.02	3.52	26.18	16.22	.12	14.02	3.52	46.71	33.90
Stephenson	C 1*b*	47.00	1.68	1.54	30.82	18.68	.13	1.68	1.54	54.99	39.05
Stephenson	C 1*c*	46.44	2.12	1.70	30.60	19.70	.11	2.12	1.70	54.60	41.18
Stephenson	C 1*d*	45.68	3.22	2.76	29.90	18.46	.21	3.22	2.76	53.35	38.59
Stephenson	C 1*e*	40.02	12.56	7.04	24.98	14.42	.31	12.56	7.04	44.57	30.14
Union	D 2	....	1.99	.36	60.79	3.36	....	1.99	.36	91.55	7.82
Union	U 66*	43.28	1.76	.92	53.60	1.02	.12	1.76	.92	95.64	2.13
Union	W 285*	42.32	3.30	1.48	51.82	1.42	.10	3.30	1.48	92.46	2.97

CHAPTER VI—CLAY MATERIAL AVAILABLE FOR PORTLAND-CEMENT MANUFACTURE IN ILLINOIS.

(By A. V. Bleininger.)

GENERAL STATEMENT.

Although the question of the clay resources available for cement manufacture seems at first to be one of minor importance as compared with that of the limestone, on closer examination it will be found that this is not the case. Clays of the physical character suitable for the economical manufacture of Portland cement are not plentiful. From the purely chemical standpoint it must be conceded that many clays would answer the purpose if they could be ground economically to a degree of fineness sufficient for chemical reaction.

There is no doubt that shales, where available, afford the most reliable clays for cement making. The chemical compositions of a number of Illinois shales worked in large quantities for the manufacture of clay products are given in the following table, and most of them are suitable for the manufacture of Portland cement.

Analyses of Illinois shales.

Location.	Silica. (SiO_2).	Alumina. (Al_2O_3).	Ferric oxide. (Fe_2O_3).	Ferrous oxide. (FeO).	Lime. (CaO).	Magnesia. (MgO).	Potash. (K_2O).	Soda. (Na_2O)	Ignition loss.
Alton	63.36	15.43	1.80	4.02	0.93	1.58	3.28	0.56	6.99
Albion	59.34	15.36	3.26	3.84	0.76	1.82	3.82	0.80	7.89
Springfield	60.31	17.74	5.04	1.96	0.41	1.96	2.88	1.07	6.71
Edwardsville	63.43	16.89	1.52	4.24	1.00	2.11	2.03	0.20	5.97
Galesburg	63.62	16.28	3.02	2.90	0.63	1.44	2.60	1.50	5.88
Streator	59.86	17.43	1.42	5.10	1.05	2.32	2.80	0.18	6.35
Danville	64.09	14.16	2.65	3.16	1.69	1.64	2.90	0.77	6.47
Danville	58.52	15.67	4.99	3.37	1.05	1.45	2.94	1.48	7.72
East Peoria	60.93	17.93	8.12	Not det.	1.33	0.91	5.01		5.73
Savanna	47.29	15.51	4.80	..do	7.33	6.19	3.71		13.11
Rodden	48.41	18.31	6.06	..do	5.73	3.13	5.65		12.79
Carbon Cliff	55.37	21.40	6.72	..do	1.76	0.65	2.42		8.75

These analyses represent but a few of the available shales of the State, owing to the fact that a survey of these materials has not yet been made. In some cases the No. 2 fire clays may be utilized for cement making, especially where the surface clay is of a loess type, i. e., too high in silica to be used alone. A mixture of loess clay and No. 2 or No. 3 fire clay could be made to answer the purpose satisfactorily.

The glacial, surface-clays of the State, though abundant, are as a rule too heterogeneous to form a reliable source of cement materials. There is no doubt, however, that in some instances such clays can be used successfully, though in every case such deposits are strictly local in character.

Owing to the fact that it was impossible to make a complete survey of the shales and other red-burning clays of the State, a start was made in this direction as far as cement-making materials are concerned by collecting samples near limestone deposits which seem to be available for the manufacture of Portland cement, and which appear to be favorably located as far as shipping facilities are concerned. Mr. F. E. Layman was detailed to undertake this work and he collected a number of samples of clay from deposits commercially available in connection with limestone beds suitable for cement manufacture. This survey was of a preliminary character, and cannot be said to include all available clays.

On arrival of the clay samples at the laboratory three kinds of tests were made. The materials were analyzed for silica, alumina, iron, lime, and magnesia. They were heated in contact with an excess of calcium carbonate to 1210° C., after which treatment the residue remaining on dissolving in hydrochloric acid and sodium carbonate solution was determined. Finally the clays were subjected to mechanical analysis by the Schulz method.

The heating treatment was preceded by mixing the clays with water, passing them through a 40-mesh sieve, and drying the resulting slip. The sieved clay was then intimately mixed with 8 parts of calcium carbonate, put into a platinum crucible, and heated in a muffle until Seger cone No. 4 (about 1210° C.) bent over in the usual fashion. The crucible was then cooled, and its contents removed and ground, and treated successively with hydrochloric acid and sodium carbonate solutions. The residue was washed on the filter, ignited, and weighed.

The mechanical analysis was carried on in the manner described elsewhere and included the determination of the residue on sieves of 20, 40, 60, 80, 100, 150, and 200 meshes. The residues left in the cans, averaging 0.0577 mm., 0.0354 mm., and 0.0167 mm., respectively, and of the material carried off in the overflow, was finally obtained.

The results of the chemical analyses of the clays are compiled in Table II. Another table—III—shows the residue left after the acid and alkali treatment, and the data of the mechanical analyses.

It is evident that a certain number of the clays are too high in silica to be considered for the manufacture of Portland cement, for it is obvious that such a clay as L3 is too siliceous, since the alumina-silica ratio is 1:7.85. Likewise a number of the other clays, assuming that the silica is in an exceedingly fine-grained condition, would be more or less objectionable owing to the fact that they would result in slow-setting cements. While this type of cement represents high quality and resisting properties and is in reality superior to the aluminous cements, it is not popular among builders because of the slowness of its action. For really important work where endurance in contact with injurious substances is a point of prime importance, the steadily increasing strength of the siliceous cements, combined with their constancy of volume is greatly to be desired.

In Table III the results of the mechanical analysis and of the insoluble residue determination are given. The fineness of the clays is indicated by the surface factor, calculated from the amounts and mean diameters of the grades passing the 200-mesh sieve. The portions remaining on this and the coarser sieves have been neglected, since the respective mean diameters were not known and since these coarser sizes do not change the factor materially. The calculation of the surface factor may be illustrated by carrying out the computation for sample L 4*a* as follows: $0.076\times(1\div0.0577)+0.0519\times(1\div0.0354)+0.3477\times(1\div0.0167)+0.49\times(1\div0.0069)=95.838$. On comparing the surface factors with the residues left after calcination to 1210° and the acid and alkali treatment, it is evident that there is no close correlation. By taking the average values of both kinds of data and assuming a linear relation, it would appear that a clay with surface factor of about 120 and above should combine smoothly with lime under the conditions stated so that no residue would be left after the acid treatment. It is evident that samples like Nos. L 13, L 3, L 8, L 9, L 2, L 7*a*, L 7*b*, and L 10 are objectionable both on account of their high silica content and their low surface factor.

Table II. Chemical analyses of clays.

All the samples marked (*) are satisfactory for cement-making purposes.

County.	Sample number.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Loss on ignition.	Remarks.
Adams	L 4*a**	49.03	11.91	10.75	8.41	5.73	13.02	
Adams	L 4*b**	50.81	10.52	7.01	10.65	5.74	13.30	
Brown	L 5	47.41	14.44	7.21	9.53	6.70	13.42	Too high in magnesia
Brown	L 6*	61.11	14.76	6.31	5.55	3.34	8.00	
Brown	L 17*	59.92	15.75	7.06	2.94	3.28	8.46	
Brown	L 18*	61.50	18.75	5.99	0.83	2.10	8.84	
Bureau	E 15*b*	49.10	27.34*a*		7.94	2.74	12.88	
Clark	L 14*	66.32	17.25	7.44	2.01	3.38	3.32	
Clark	L 15*	68.20	14.09	9.94	1.57	3.46	2.42	
Edgar	L 12*	58.90	19.09	8.11	1.56	3.52	6.18	
Edgar	L 13	74.24	13.58	5.73	1.58	1.86	2.02	Too high in silica
Hancock	L 3	76.00	9.68	5.76	1.80	1.58	3.62	do
LaSalle	E 1*b**	49.02	20.14*a*		13.82	2.10	15.46	
LaSalle	E 6*e**	53.48	22.36*a*		7.64	1.78	14.66	
Montgomery	L 8	71.65	12.69	6.32	1.51	1.60	5.10	Too high in silica
Peoria	L 1*	57.67	21.60	6.63	1.61	3.21	6.80	
Pope	Bu 21*	60.75	20.49	7.30	.52	1.73	6.05	
Pope	Bu 22*	59.97	21.00	7.15	.60	1.58	5.54	
Pope	Bu 23*	59.90	20.27	6.80	1.14	1.66	6.70	
Randolph	L 9	75.93	11.96	3.48	2.01	2.04	3.20	Too high in silica
Randolph	W *a**	57.55	23.51	6.05	2.13	3.39	5.83	
Randolph	W *b**	63.22	16.98	5.67	2.30	3.16	7.50	
Rock Island	L 2	77.31	9.20	5.11	2.31	1.86	3.30	Too high in silica
Schuyler	L 7*a*	73.78	16.20	1.76	0.63	2.09	4.63	do
Schuyler	L 7*b*	73.66	16.37	2.06	0.63	2.10	4.85	do
Union	L 10	73.10	13.45	5.33	2.12	2.18	2.86	do
Union	L 11*	64.78	18.17	6.74	1.43	1.69	5.62	
Union	W 286	71.24	13.74*a*		5.32	1.50	7.66	
Wabash	L 16*	55.95	18.89	8.09	2.31	3.06	8.74	

a Including Fe_2O_3.

Table III. Mechanical analyses of clays.

Clays marked (*) are considered suitable for cement making.

County.	Sample No.	Percentage residue on sieves of mesh—							Residue in can—			Carried off by overflow—Average diameter 0.0069mm.	Residue left after ignition and acid and alkali treatment of sample.	Surface factor.
		20.	40.	60.	80.	100.	120.	200.	First.[1] 0.0577.	Second.[1] 0.0354.	Third.[1] 0.0167.			
Adams	L 4*a**	1.55	0.28	0.26	0.21	0.09	0.28	0.31	7.16	5.19	34.77	49.90	28.7	95.838
Adams	L 4*b**	....	0.08	0.07	0.06	0.04	0.09	0.18	9.76	23.86	44.38	21.48	23.88	66.138
Brown	L 5	0.57	0.11	0.11	0.11	0.04	0.12	0.41	11.34	6.75	44.71	35.73	18.45	82.451
Brown	L 6*	....	0.13	0.50	0.52	0.27	0.35	0.37	5.66	40.22	17.30	34.68	19.80	72.980
Brown	L 17*	0.15	0.46	0.48	0.83	0.19	0.98	1.69	9.84	43.95	17.81	23.65	73.31	59.064
Brown	L 18*	1.77	0.76	0.19	0.09	0.51	0.53	0.92	18.73	28.93	17.18	31.89	73.25	67.904
Clark	L 14*	....	0.02	0.03	0.03	0.05	0.28	3.38	6.94	52.73	15.81	20.73	49.15	55.604
Clark	L 15*	6.60	0.25	0.17	0.13	0.14	0.72	2.97	29.12	32.03	12.10	15.77	57.05	44.203
Edgar	L 12*	0.58	0.18	0.07	0.06	0.03	0.06	0.28	10.97	32.45	20.28	35.04	7.48	73.998
Edgar	L 13	0.09	0.02	0.11	0.09	0.11	1.27	10.40	41.42	28.80	9.00	8.79	42.43	33.452
Hancock	L 3	2.80	2.71	3.41	2.25	0.91	2.57	4.35	17.15	15.11	29.16	19.52	....	53.000
Montgomery	L 8	3.83	2.77	5.04	3.30	1.38	3.02	3.59	15.60	32.79	14.58	33.30	75.55	68.922
Peoria	L 1*	2.62	1.20	0.17	0.30	0.05	0.03	0.22	0.34	5.77	19.46	69.84	10.57	114.598
Randolph	L 9	....	0.10	0.13	0.11	0.10	0.35	1.38	42.70	40.69	6.26	8.28	48.90	34.643
Rock Island	L 2	0.19	0.57	1.46	0.91	0.40	0.69	1.06	19.28	15.13	41.77	17.54	....	58.225
Schuyler	L 7*a*	....	0.03	0.07	0.07	0.09	0.24	1.73	32.54	42.93	12.01	10.29	29.45	39.880
Schuyler	L 7*b*	....	....	0.16	0.12	0.14	0.21	1.46	40.27	32.68	13.04	11.88	36.08	41.238
Union	L 10	1.41	0.43	0.36	0.27	0.14	0.33	0.64	20.29	46.00	13.15	16.98	77.15	48.983
Union	L 11*	....	....	0.08	0.08	0.04	0.21	0.25	24.35	42.80	14.25	17.94	40.42	50.842
Wabash	L 16*	0.92	3.12	8.24	4.03	2.46	4.55	5.71	11.12	22.65	15.72	21.48	50.69	48.874

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[1] Average diameter in mm.

CHAPTER VII—DESCRIPTION OF CLAY DEPOSITS SAMPLED.

(Compiled from notes of F. E. Layman.)

INTRODUCTION.

The field work on clay investigations by no means attempted to cover the State nor to include all clays which are suitable for cement making. The method of procedure was to visit the locations where the limestone had been found to be of a quality sufficiently good for Portland cement, and to restrict the examination of the clay to these limestone areas. Each of the most promising limestone locations was made the center of an area about 5 miles square, and the clay was investigated in each direction for about 2½ miles. In this work advantage was taken of all railroad cuts, streams, and ravines where the clay might be exposed. For each clay location, roughly speaking, the territory was crossed in one direction with lines about 1½ miles apart, and then the vicinity was examined along lines at right angles. The region was thoroughly criss-crossed and examined in this manner.

Not all locations, however, admitted of this extensive work, as some were unfavorable either from the standpoint of transportation or because the character of the clay in the immediate vicinity of the limestone was not promising. Samples were taken only where the clay occurred in such bulk as to make the deposit commercially valuable, and where it lay within reasonable distance of a railroad. The character of the deposits also influenced the selection of samples. If the clay contained pebbles or mineral detritus no samples were taken even though the deposits were otherwise favorable. The method of sampling was to cut back into the face of the bank beyond the zone of oxidation and to take a thin slice from the fresh exposure (Pl. XIX). The sample thus roughed out contained, as a rule, about 200 pounds. This was mixed and reduced by quartering to a 50-pound sample which was placed in a bag, together with a wooden tag on which the number of the sample was carved. Shipping directions on the outside of the sack also bore the number of the sample so as to permit no possibility of error through confusion of numbers.

The following description of samples and of clay occurrences is arranged alphabetically by counties and contains references to the field numbers of limestone samples described in the preceding chapter. Chem-

Prospect pit for shale sample.

ical analyses of the limestones are presented in Table I and of the clays in Table II. Physical analyses of clays appear in Table III. Those samples which seem suited to the manufacture of Portland cement are marked with the asterisk (*).

ADAMS COUNTY.

Limestone (C 17*) occurs 5 miles east of Mendon but the territory examined for clay centers at the limestone property near the house of William Quigg, 1½ miles north of Mendon. Unfortunately this limestone was not analyzed. A 200-foot well on the premises is said to have penetrated about 100 feet of stone. The limestone is overlain by bluish clay shale which weathers yellow. This blue clay extends over all the territory examined and appears to vary considerably in thickness. It is covered by an overburden of top soil 2 to 4 feet thick. North of the Quigg property the country is hilly and the clay beds appear on the slopes.

L 4*b*.* The clay was traced northwest, down Webb creek, and a sample was taken on the property of Mr. Robert Cannell, where the best exposure was observed to be 10 feet thick. This clay forms the bed of the creek and extends at least 10 feet deeper, according to a boring reported by Mr. Cannell. This shale is rather hard but is easily slaked by water.

L 4*a*.* Across the road and higher up the hill there is a 6-foot exposure of yellow to blue clay, evidently derived from the underlying shale. A sample was taken here. The relations are indicated by the following measurements:

Section near Mendon.

		Feet.
5.	Clay, yellow to blue	6
4.	Shale, soft	2½
3.	Limestone	1½
2.	Shale, medium-hard	6
1.	Shale (reported) below creek level	10

The country south of the home of Mr. Quigg is admirably adapted for plant location. A short distance to the north plenty of blue clay was observed under a top-soil cover of about 3 feet. The thickness of the deposit between Mr. Quigg's house and the Burlington tracks cannot be estimated since the country is level and the water courses have not cut down sufficiently to expose much clay. A spur from the Burlington tracks over ground of easy grade to the suggested plant site would probably not exceed three-fourths mile in length.

BROWN COUNTY.

An extensive limestone exposure (C 20) occurs 3 miles southwest of Versailles on the property of Mr. Foster Wiley, in the NW. ¼ sec. 26, T. 2 S., R. 3 W. Another limestone exposure is found on the property of Mr. Joe Myers, about one mile southwest of Versailles. The region is deeply eroded and the hills which rise 25 to 150 feet above the streams reveal considerable clay of the character represented by the samples.

L 5. A sample was taken from the base of the hill west of the house of Mr. Charles Bradberry and one-half mile east of the limestone in section 26. This hill is 75 feet high, and when the sample was taken was so covered with rank vegetation that the upper portion could not be examined readily. The sample represents an exposure of 15 feet. A spur from the Wabash to this place would prove expensive.

L 6.* A sample was taken also from the property of Mr. Joe Myers, about half way up the 65-foot hill. In this hill clay alternates with sand and gravel but appears to predominate. Because of slides, the sample is not regarded with confidence. Prospecting should be done with an extension auger. The site of sample L 6* could be reached more easily than the other by a railroad spur, but in general, judging from the character of the limestone and of the clay deposits the region is not favorable for a cement plant.

L 17,* 18.* Samples were collected representing shale which is commonly exposed along roads and in ravines along the eastern part of Brown county from Camden in Schuyler county to the vicinity of Cooperstown. The region is deeply eroded and the shale varies in depth below the surface. L 17* was collected from a 10-foot exposure by the roadside near Scott Mill, on the property of John Chamberlain. L 18* was taken from a 6-foot exposure opposite Scott Mill on the Jesse Gibson land. These shales might be used for cement manufacture in connection with limestones C 26, 27,* and 28,* but the lack of railroad facilities would hinder exploitation of such cement resources as the county possesses.

BUREAU COUNTY.

E 15, *b*. Limestone sample E 15, *a*, previously described as from near Marquette, is accompanied by a 7-foot shale. The analysis is shown in Table I.

CLARK COUNTY.

In the vicinity of Casey where limestone S 9* was collected no shale or clay of value was found. A variable sandy clay covers the region.

L 14.* A sample was taken about 1½ miles northeast of Marshall, where a cut along the C., C., C. & St. L. railroad exposes 8 feet of shale under a 6-foot covering of glacial clay. This might be used in combination with limestone S 51,* but the materials sampled are near the minimum thickness which would warrant operations. Drilling might reveal deeper deposits.

L 15.* A sample was collected from a 5-foot exposure of shale occurring 1½ miles north of Marshall on the property of Mr. William English. The sample was selected 150 yards south of the house, along the creek. The bed is too thin for exploitation, but may be underlain by additional shale of suitable character.

EDGAR COUNTY.

L 12,* 13. Large amounts of shale suitable for Portland-cement manufacture were examined in T. 14 N., R. 11 W., in the vicinity of Baldwinsville. L 12* was collected from a 20-foot exposure at a bridge on the J. E. Garvin property, about 1 mile northwest of St. Aloysius church. L 13 represents a 6-foot exposure along the creek 300 yards north of the church where the following measurements were made:

Section near Baldwinsville.

	Feet.
Soil	2
Limestone	2½
Shale, blue hard (L 13)	6
Shale (below creek)	+
Limestone (outcrops to south)	+

In connection with limestones S 50* which occurs 1 mile east of Baldwinsville, these shales are promising; but of course the nearest railroad lines are 4 to 6 miles distant.

HANCOCK COUNTY.

L3. Clay was investigated in the vicinity of Niota. The town is situated on flat ground, but about one-quarter mile back rises a line of hills in which limestone (C 40,* 41*) is found. The clay in thickness varying up to 100 feet, overlies the limestone. It may be found all along the hills back from the village. The clay is very sandy and of alluvial origin; it is so changeable in quality as to be a suspicious cement material. In all cases, however, the overburden on this clay is not more than a few feet thick.

L3. A sample was taken three-fourths mile west of Niota on the property of Conrad Freitag on the south side of the road about halfway up the hill. At this place the limestone is possibly 50 feet thick and is overlain by 30 to 100 feet of clay. A good plant location may be had towards Niota about one-eighth mile from this deposit or about 1¼ miles west of the Santa Fé tracks. However, taking into consideration the changeable nature of the clay and the physical character of the country, the location is not a good one for Portland-cement manufacture.

JACKSON COUNTY.

The region about Grand Tower was thoroughly examined, but no clay worth sampling was found. The characteristic clay of the region is sandy alluvium or loess, such as is found near the Mississippi river from Rock Island south. Limestone is exposed in abundance (S 5*x** and S 57*a**), but is buried from 6 to 40 feet under this sandy clay. Between Grand Tower and Murphysboro a large deposit of shale was observed from the train; and though no sample was obtained it is the writer's opinion that shale may be found along the Illinois Central tracks within commercial distance.

LA SALLE COUNTY.

E 1*b*.* Shale, 3½ feet thick, occurs interbedded with limestone E 1*a*,* etc., at the plant of the German-American Portland Cement Company. Analyses are shown in Table I.

E 6*e*.* A sample was taken from a 5-foot shale similar to the last and occurring beneath the limestone at the quarry of the Chicago Portland Cement Company at Oglesby.

MONTGOMERY COUNTY.

An 8-foot exposure of hard, blue shale in the vicinity from which limestone (694*) is reported to have been collected. (sec. 32, T. 9 N., R. 4 W.) is promising in appearance but is so deeply covered as to make stripping impracticable. No sample was collected.

L 8. Limestone (698*) collected from one-eighth mile north of Quarry (sec. 2, T. 8 N., R. 5 W.) is about 20 feet thick. The clay sample was taken from a bed 6 to 8 feet thick, which is exposed at the base of the hill 100 yards north of Quarry, and which has only 2½ feet of overburden. A representative section of clays in the vicinity is as follows:

Section near Quarry.

	Feet.
Top soil	2
Joint-clay	4
Sand	2
Gravel	10 to 20
Clay, whitish-yellow (L 8)	6 to 8

Since this clay occurs with workable overburden in only a small area, and the favorable limestone occurrence is also limited in extent, the locality is considered unattractive for Portland-cement manufacture.

Other clay was sought within a 2-mile radius of Quarry without success. It is reported by Mr. M. T. Kiggins of Hillsboro that several feet of promising blue clay of fine grain underlies the limestone. Its thickness and quality would seem to warrant drilling test holes.

PEORIA COUNTY.

The vicinity of the George Sword's estate (SE. ¼ sec. 10, T. 8 N., R. 7 E.) was examined for clay or shale which might be used with the limestone at the quarry (Bu 9*). Investigation included the region within 1¼ miles north of the Iowa Central railroad and extending from Maxwell to a locality about 1 mile east of the limestone. The region is hilly and is covered by a sandy, loess-like clay of slight plasticity, which is locally 75 feet thick. This did not warrant sampling. On the Sword's estate a fine-grained, bluish shale, 4 feet thick, underlies the limestone. It can be traced a mile down the creek but lies too deep for successful excavation, and does not outcrop favorably in the region examined.

The region 3 miles northeast of Princeville, where limestone Bu 8* and E 26* occurs, was examined for clay deposits. The rolling prairie is not sufficiently eroded to offer many exposures.

L1.* A sample was collected 1½ miles north of the Streitmatter house (See Bu 8*), along a creek on the property of Mrs. William Long, one-eighth mile west of the highway bridge. This is in Valley township, Stark county. The exposure includes 2½ feet of soil underlain by 5 feet of blue and yellow clay and 4 feet of blue shale. Only the blue clay and shale were included in the sample. The clay and shale persist over the region and are exposed, about 3 feet thick, beneath the limestone along the creek northeast of the Streitmatter house and under the limestone at the Jackson house, 1 mile southeast of the clay sampled.

The maximum haul between the limestone outcrop and the clay deposit sampled would not exceed 1½ miles, and clay could probably be found at a shorter distance. The physical character of the country is admirable for plant location, and water is said to be plentiful; but the distance from the nearest railroad would make this general location doubtfully suited for Portland-cement manufacture.

POPE COUNTY.

Bu 21,* 22,* 23.* Examination was made by Mr. Burchard, of the U. S. Geological Survey, of shales and limestone on the Edward B. Clark property known as Limestone Hill. This lies west of Golconda in sec. 26, T. 13 S., R. 6 E., and offers excellent opportunity for cement manufacture (Bu 20*).

Bu 21* is from a 5- or 6-foot roadside exposure of a bed of shale which is probably 25 feet thick. Bu 22* is from a 5½-foot prospect hole in the creek bank, and occurs in the same horizon as Bu 21.* Bu 23* is from a 6½-foot exposure in a prospect pit.

The overburden on the shale represented by Bu 21* and 22* ranges up to 40 feet. The shale from which Bu 23* was taken underlies the limestone represented by Bu 20,* and if used in connection with the shale interbedded with the limestone would probably furnish enough material for a cement mixture.

RANDOLPH COUNTY.

The territory within a 3-mile radius of Red Bud was traversed in search of clay which would be usable in combination with limestones W 253,* and 254.* In general, the top soil is underlain by 4 feet of micaceous joint-clay and a varying amount of sandy clay of low plasticity. No promising sample was collected. At the Red Bud brickyards several feet of blue shale is said to underlie the limestone. This may warrant prospecting.

L9. A sample of clay was collected from the Brickley property at Prairie du Rocher (sec. 20, T. 5 S., R. 9 W.) in the vicinity of the 75-foot limestone, U 47.* It represents the sandy clay covering the flat pasture-land and is thought to be representative also of the gritty clay which occurs in great quantities on top of the limestone bluffs; where it underlies 4 feet of micaceous joint-clay and a varying cover of top soil. The sample probably represents a similar stratum at Red Bud, and proves to be worthless for cement manufacture. This fact would render the working of the underlying limestone expensive. The search was extended east of the bluffs over a north-south strip, 2 miles wide and 5 miles long, but no promising clay was found. Since, however, the limestone is usable and the location for a plant is otherwise excellent, it may be that more minute examination would be warranted.

W *a,** *b.** Samples of shale collected by Mr. Elmer Grant from the 43-foot shale at Menard (see section under limestone notes for this county) are referred to in the table of clay analyses and appear promising.

ROCK ISLAND COUNTY.

In view of the excellent limestone exposures southeast of Milan along Mill creek (Bu 15* and 16*) a careful search was made for clay or shale for use with it. The flood plain of Rock river is about three-fourths mile wide at this place, and is bordered on the south by bluffs in which occurs the limestone. The clay on the bluffs is sandy and loess-like, and is not suited for the desired purpose. The alluvial clay of the bottoms is not well exposed by the streams and is doubtless variable in character.

L2. A sample was collected about one-half mile west of the Monmouth road, and 100 feet south of coal bank road and the Chicago-Rock Island tracks, where 6 feet of yellow clay is exposed in the west bank of a tributary to Rock river. A short distance away appears an abandoned brick yard; and an abandoned limestone quarry lies one-fourth mile north of the deposit sampled. Although the limestone of the vicinity appears excellent and a plant site could be selected easily, the character and amount of available clay is discouraging.

SCHUYLER COUNTY.

An examination of clays in the vicinity of Frederick was desirable in view of the limestone bluffs near at hand and the character of limestone samples C 45* and C 46.* At the time of field work, however, the high water in Illinois river affected the tributaries and made a complete examination impossible. The clays appear variable in extent and hence would require systematic borings. Suitable plant locations for a cement industry occur along the creek within moderate distances of the railroad.

L 7 *a, b*. Samples were collected from the clay bank of the Frederick Brick Company as indicated by the measured section. L 7 *b* is said to be suitable for paving-brick manufacture, and is reported by Mr. Hill, of the company, to extend at least 30 feet below creek level.

Section at Frederick.

		Feet.
6.	**Top soil**	2
5.	**Joint-clay, yellow**	6
4.	**Clay, sandy, light gray (L 7*a*)**	8
3.	**Coal, impure**	2
2.	**Shale, blue (L 7*b*)**	10
1.	**Shale, (reported below creek)**	30

STARK COUNTY.

See description of sample L 1* under Peoria county.

UNION COUNTY.

L 10. A clay sample was taken at the quarry of the Union Stone and Lime Co., at Anna (U 66,* D 2), where it covers the limestone to a depth of from 6 to 10 feet. This is characteristic of the yellow, sandy, surface-clay in this region.

L 11.* A sample of shale was taken about 4 miles north of Anna and 2 miles south of Cobden, on the property of Silas Lingle (sec. 6, T. 12 S., R. 1 W.). The shale is fine grained and uniform, and outcrops along the creek one-half mile east of the Illinois Central tracks, and about one-eighth mile north of the Lingle home. The exposure here is about 10 feet deep, overlain by 2 feet of limestone and top soil of about 2 feet. This shale is said to extend 10 feet below the creek bed. The deposit offers fine shipping facilities, and appears to be of considerable extent. The main line of the Illinois Central could easily be reached across comparatively level ground of the creek bottom. Perhaps suitable shale of similar character can be found nearer the property of the Union Stone and Lime Company, where the limestone appears available for cement manufacture.

W 286. A sample of shale was collected from the 40-foot bed described in the limestone section near Korndahl station, in the NE. ¼, SE. ¼, sec. 1, T. 13 S., R. 2 W.

WABASH COUNTY.

L 16.* A sample was taken near Mt. Carmel on sec. 36, T. 1 S., R. 13 W. The shale at this point is 40 feet thick, and is located on a spur of the Southern railroad. The sample was taken from a shaft sunk by Mr. W. A. Stansfield of Mt. Carmel. No limestone was found in the region.

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